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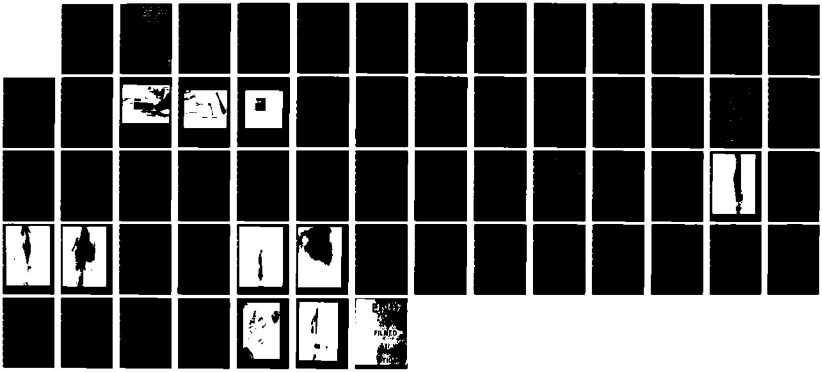

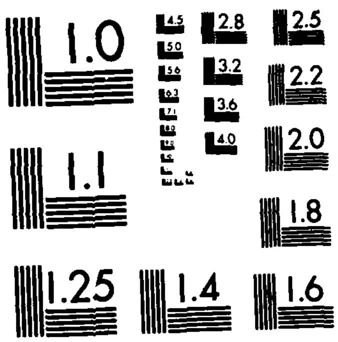

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Program Engineering &
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Washington, D.C. 20591

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An Experimental Investigation of the Efficacy of Automated Weather Data Transmission to Aircraft in Flight

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Athens, Ohio 45701

December 1982

Final Report

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16. Abstract

Results of a flight evaluation of a cockpit weather data device operating with actual weather are reported which indicate that valuable and useful weather information can be given automatically to the pilot in flight to aid his decision making. Both text and graphics were investigated and found to have the potential of increasing aircraft safety.

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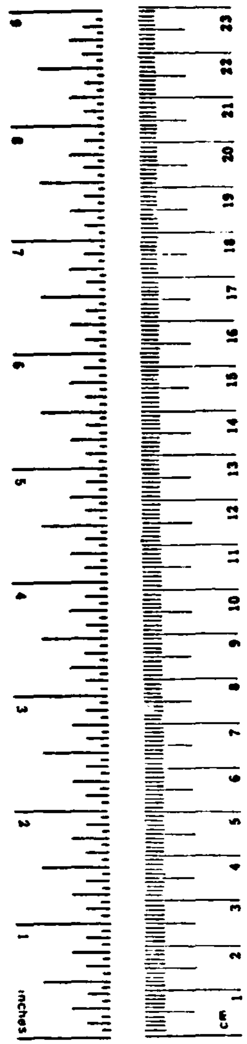
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

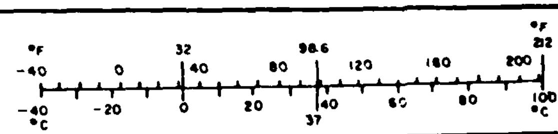
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



60 mph = 52.1 knots (nautical miles per hour)
60 mph = 88'/sec
$1g = 32.2'/sec^2$

1 mph = .87 knots
1 knot - 1.15 mph

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LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

I. SUMMARY AND CONCLUSIONS

A flight evaluation of an airborne device for uplinking weather information to the pilot in flight has been successfully completed. This device, a cockpit weather dissemination system (CWDS) designed and built by the MITRE Corporation, has the capability of providing to the pilot both text and graphics information which has been uplinked to the aircraft over a part of the VOR voice channel.

The CWDS was found capable of providing radar reflectivity patterns which were used by pilots to adjust their flight paths and thus avoid turbulent areas. The synoptic view available from the radar located in Columbus, Ohio gave the pilots a perspective that is not even available from on-board weather radar. This was found to be a significant advantage in maximizing the efficiency of the flights and minimizing the discomfort to the crews and passengers. The emphasis was on light, general aviation type operations although the results are directly applicable to commercial and military operations.

The impression made with the 16 pilots who had the opportunity to fly with the CWDS was that the CWDS is indeed a useful device for providing the pilot with excellent decision-making information. The several pilots who completed formal questionnaires concerning their experience and impressions of the device were consistent in recognizing the advantages offered by the CWDS. Some were very enthusiastic concerning the benefits the CWDS offers. At the very least, the respondents felt that the CWDS offered a useful service for those who cared to invest in the equipment. There were no negative responses from participants concerning the appropriateness of such a device for improving safety of flight. In fact, most felt that it would truly be a factor for improving safety.

This flight evaluation was accomplished by a team at Ohio University and had as a fundamental purpose that of determining whether providing graphics and text weather data in the cockpit can indeed aid the pilot in completing his flight safely. This decision-making information allowed consideration of alternate possibilities for his route when, for example, thunderstorms blocked the planned route. Further, it was important to learn whether the mechanization, viz., a keyboard/display and dot-matrix printer would provide satisfactory service in flight. Concern was given to the pilot interaction with the devices while he was required to fly the aircraft.

Three VOR stations, roughly on a line through central Ohio, were equipped to uplink weather data. Most of the data collection was accomplished in central and southeastern Ohio during the summer of 1982. On two particular occasions during this period, fortuitous weather conditions prevailed for demonstrating the efficacy of the CWDS for aiding in completing cross-country flights when thunderstorms were a formidable impediment to the routine completion of the flight. Even though the coverage available involved but a small portion of the route, the aid that was provided was so dramatic that no one on board the flight failed to recognize the value and importance of the CWDS.

Twenty-one flights were completed with 16 different pilot observers in all having the opportunity to observe the operations of the device. Nine flights produced useful data in the sense that the radar pictures revealed interesting conditions. Some specific conclusions reached following approximately 24 hours of flight are as follows:

1. The CWDS provides a valuable, unique capability for the pilot to obtain graphics presentations while airborne.

2. The availability of graphics portraying radar reflectivity patterns has been found to be valuable with respect to completion of cross-country flights into areas where thunderstorms exist.

3. Because the probability of encountering turbulence is reduced, safety is enhanced. Passenger comfort is clearly improved.

4. Text data which is available from an automatic uplink with the CWDS is not only obviously useful in itself, but it is also quite valuable in reducing radio voice channel congestion. The passive nature of the one-way data uplink means that the data is on hand in the airplane, and its acquisition is not a function of how many other pilots are on the microphone requesting various other weather data items. As the weather gets to be a more critical factor in the safety of the flight, the more valuable the CWDS automatic uplink becomes.

5. The principal virtue of the NIXDORF keyboard used for this evaluation of the CWDS is its availability on the present market. The negative aspects identified are:

a. Small keys that are difficult to locate and operate in even light turbulence conditions. Too much time is required by the pilot to operate the keyboard.

b. Lack of tactile characteristics that lets the pilot know that he has activated a given key.

c. Non-standard keyboard layout referencing either computer interfaces, present ARINC keyboards, or telephone keyboards.

d. LED display cannot be read in sunlight conditions. Liquid crystal displays would be more desirable as would some gaseous discharge displays.

6. The dot-matrix printer has some benefits and disadvantages when compared to the more commonly used cathode ray tube display device. Its advantages are its low cost, simplicity, and hard copy which makes it very appropriate for research or evaluation work where preservation of information is desirable for documentation purposes. It also allows for comparison of a time sequence of pictures which permits the establishing of trends. Trends, of course, are useful in predicting what may happen in the immediate future. This nowcasting is being recognized as a specialized area of forecasting which the pilot may do well to add to his skills. One

disadvantage of the printer is the lack of contrast which can, for example, be produced with color CRTs. Annunciation of hazardous weather areas are not as easily accomplished. The CRT will always have the advantage of providing capability for dynamics which means it can be made to handle aircraft positional inputs, when and if this becomes desirable.

7. The capability to shift the coordinate reference center on the CWDS is valuable.

8. Scale change flexibility available on the evaluation model of the CWDS is greater than that needed. The 256 scale divided by 9 provides an expansion which does not seem justified by the resolution of the basic radar information. False confidence may be created in doing this. The 256/1 and the 256/3 are two particularly useful scales.

9. A major increase in usefulness would be obtained by providing on the printout of the weather radar picture the location of the aircraft. Clearly, this is not simply accomplished, but with RNAV equipment on board the aircraft, the basic information is available. Referencing it to the radar picture in the most inexpensive manner would require operator action and this might be an undesirable burden.

10. The first weather radar picture obtained, especially when in IMC, is worth the proverbial 1,000 words. The anticipation by the crew of the receipt of the first picture is remarkable.

11. Format of the text data containing the sequences provided by MITRE needs modifcation to make it consistent with the format found with teletype or weather data bank products.

12. The laboratory-type equipment reached the limits of its endurance in this evaluation program and thus pointed to the need for wiring and fabrication practices more consistent with airborne-type hardwares. Faults accounted for an undesirably large number of abortive attempts to collect airborne data.

13. The form, weight, and power requirements of the CWDS equipment was appropriate for use in the evaluation which involved small, general aviation aircraft. Clearly, the industry will have many exciting ideas how such equipment should be packaged to have maximum appeal to the aviation community.

14. An observed range of operation of over 90 miles from the VOR when operating at 10,000 feet appears to be adequate. An improved capability to operate with lower signal-to-noise levels would be desirable, however, especially if ground use would prove to be desirable for fixed-base operators and even pilots in their homes for preflight planning purposes.

15. The virtues of a multi-station, multi-radar net became quite evident during this evaluation. The broader the radar and VOR coverage areas, the greater the utility, obviously. Tuning VORs in the evaluation

program was undesirable because of the dedicated receiver being located in the covered box usually located towards the rear of the airplane. Implementation to use existing panel-mounted VOR receivers in the aircraft would eliminate this problem.

16. The passive efficient character of the CWDS is an extremely important asset, especially when electromagnetic wave polution abounds and EMI seems to be an ever-increasing concern.

17. Pilot acceptance of the CWDS, even in the evaluation form was very high, principally because it provided heretofore unavailable, valuable information to the pilot for decision making. Its relation to flight safety was obvious to all pilots who observed it in operation.

18. Evidence exists that avionics manufacturers are interested in producing a CWDS-type product.

II. INTRODUCTION

During the summer of 1982, opportunities became available to allow practical assessment of the performance and usefulness of the cockpit weather dissemination system (CWDS) developed by MITRE under FAA sponsorship. Earlier work [1] examined pilot response to acquisition and availability of weather data in the cockpit. Approximately 25 pilots were exposed to the uplink of prerecorded weather information, and their reactions were positive that this type of information would be useful to safe conduct of flights in small aircraft.

This report presents pilots' responses and impressions concerning flight operations where live data is uplinked on a near-real time basis and the pilot is faced with the practical situation of maneuvering an aircraft so as to accomplish tracks which permit safe operation by avoiding significant weather cells.

The source of the weather radar information used in this study is the National Weather Service's C-band WSR-74C Radar at the Port Columbus International Airport. The source of the text data is the National Weather Service weather data bank in Kansas City. Both of these data are transmitted over telephone lines to the Metrek Division of the MITRE Corporation at McLean, Virginia where it is processed and formatted in a serial data stream and forwarded again over telephone lines to the Zanesville VOR, the Rosewood VOR and the Appleton VOR in the central Ohio area. A modem designed and installed by MITRE is provided at each VOR for removing the signal from the line and modulating the VOR voice channel with the weather information. Frequency shift keying is used [2].

Twenty-one flights were accomplished. Six of these produced rather spectacular results in that very significant weather was present and the flights were able to negotiate safely a flight track among the weather cells that were present.

Aircraft used were a Beechcraft Model 35 Bonanza and a Beechcraft Model 36 Bonanza. Both are representative of 140 to 170 knots single engine general aviation aircraft grossing at 3000 to 3600 pounds. On-board weather radars are typically not found in these types of aircraft.

These flight observations are the first obtained using the CWDS with near-real-time weather. This, of course, means that correlation between the uplinked data and visual observations can be accomplished. The term "near-real-time" is used to denote that the data coming from the weather radar, in particular, is delayed one to two minutes, principally, because of the requirement to send the mass of video data by means of the relatively slow 2400-baud rate required by the phone lines. Radar image update rate is also a factor. The commercially available digital encoding system for radar data produced by the Enterprise Electric Co., Enterprise, Alabama, and commonly used by TV stations for their news show, is used to acquire initially the weather radar reflecting pattern. Future plans could make use of the RRWDS (Remote Radar Weather Data System) now being deployed.

This work allowed the first practical evaluation of the potential of the CWDS weather uplink capability. The information contained in this report comes from experienced pilots with a total piloting experience of over 30,000 hours. The author, who performed the majority of the flights either as an instructor pilot or the pilot responsible for data collection, is keenly aware of the limitation of general aviation operation due to weather, in particular. A very important motivation factor for considering the CWDS as an aid to the pilot, in particular, the general aviation pilot, is the statistic that 40% of fatal accidents involving GA-type aircraft are weather related. A study by Ohio State University for NASA reports that a principal difficulty pilots experience in making good decisions is the timeliness of the weather data dissemination. Word of mouth transmitted over sometimes congested radio channels is known to be inefficient and sometimes impossible when critical weather is present and a great number of pilots are working the radio to obtain specialized data to meet their individual needs. Old data that is obtained can sometimes be worse than none at all.

The general aviation pilot commonly flys without backup dispatch capability, such as the airlines provide, and, as a result, is out there in the airspace alone. No one is watching his flight route who will call him to advise that there are weather problems. It is his sole responsibility. It is reasonable, therefore, that this pilot, also with major responsibilities for persons and property, should have quality information and sufficient quantity for proper decision making. By proper it is meant that the information is such as to permit determination of safe courses of action.

The work statement for this project calls for execution of flight tests and evaluations of the cockpit weather display (CWDS) to include an analysis of the CWDS' usefulness as a hazardous weather avoidance device. This has been done through the 21 discrete flights which were made to allow for evaluation of efficacy and also the permitted demonstration to interested individuals that useful data could be uplinked in a simple straightforward manner.

III. AIRBORNE EQUIPMENT

Three discrete pieces of electronic equipment comprise the cockpit weather display system used for this evaluation. First, there is the NIXDORF display/keyboard with which the pilot interacts. Its alphanumeric keyboard and LED readout provide the capability of selecting specific items that have been automatically stored for printout and of adjusting scales and coordinate centers relating to the graphic displays. By inspection of the LED display the pilot may determine if data is being uplinked, whether stored data exist, or whether printing action is in progress. Indicated, also, are other actions such as input of new coordinate centers or whether other keyboard-initiated actions are being processed. A photograph of the display is shown in Figure 1.

Second, there is the processor unit. With this particular processor is a VHF navigation-receiver (Collins Microline Model) provided for convenience of CWDS installation and to make the whole assembly more flexible for use in different aircraft. Coupling with the aircraft system is achieved by simple connection of the processor box to the aircraft 12-volt, DC system and to the VHF navigation antenna line by means of a splitter. The Texas Instruments Model TM990 microprocessor is also housed in an 18" by 18" by 12" aluminum suitcase-like box. This oversized box provided by MITRE allows for storage of the keyboard and printer for shipment. This box also houses the special processor/memory board designed by MITRE. Access to this box is through the top cover and is necessary only if one wishes to retune the nav receiver to another station. The off-on switch and cable connectors are mounted on the external surface of the box. Should only the essentials be housed, a box of 3" by 12" by 15" only would be required for the prototype unit.

A photograph of the box used for the flight evaluations is given in Figure 2. Again, it is important to note that this box was one selected for convenience and there is no intent to suggest that it is at all appropriate for a final general aviation product.

The third item of the equipment set is the model LK3000 dot-matrix printer which is shown in Figure 3. This printer is an off-the-shelf product manufactured by Alphacon and costs $300. It provides not only for text information, such as is required for weather sequences, but also allows for construction of graphics necessary, for example, with the depiction of radar reflectivity patterns.

Figure 4 shows a block diagram of the airborne system dedicated to this evaluation program. This has been successfully flown in the Ohio University DC-3, a Beechcraft Model 35 Bonanza and a Beechcraft Model 36 Bonanza. Most of the measurements were made with this last aircraft. Almost any aircraft would really have been suitable; however, these were the ones most readily available.

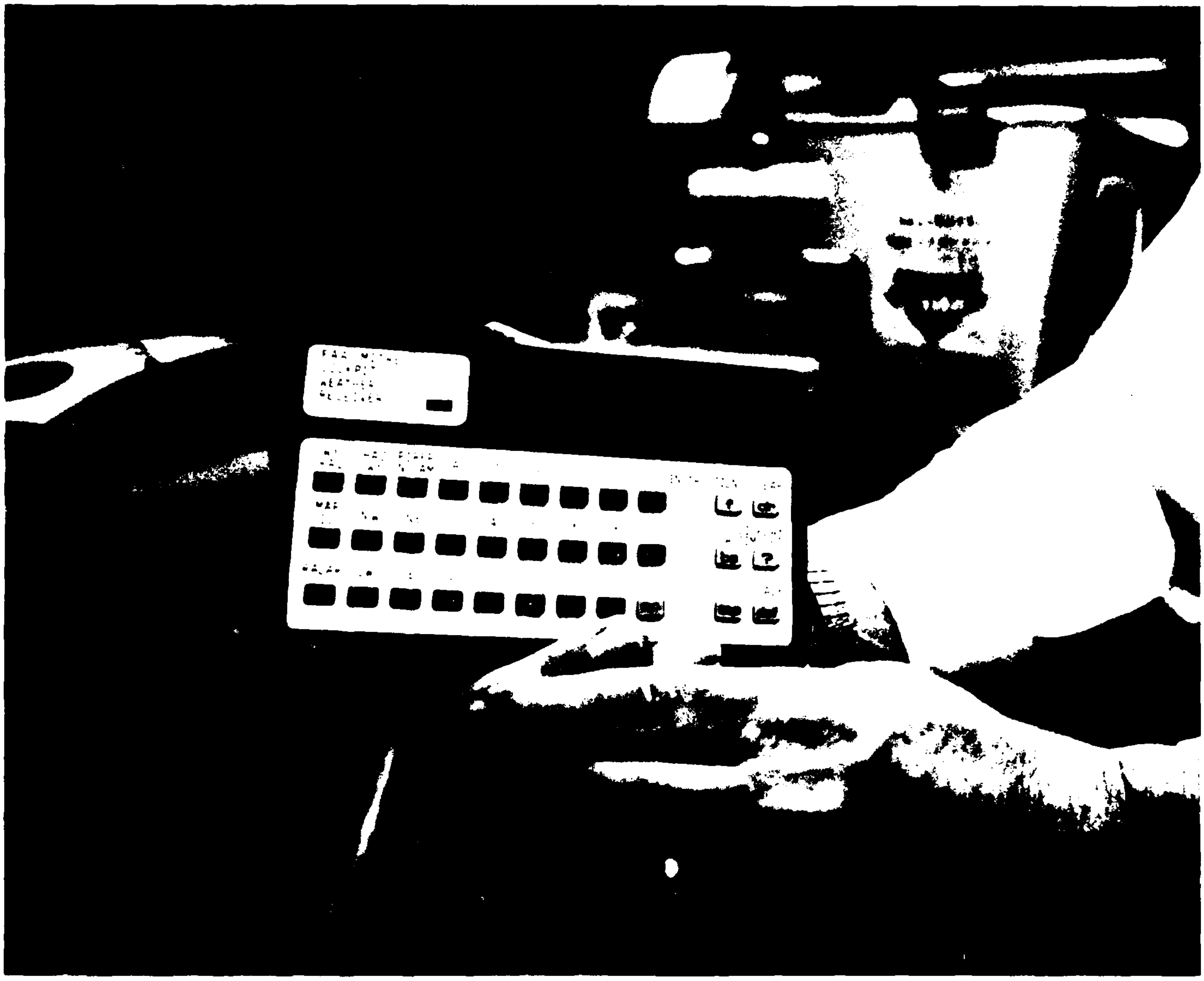

Figure 1. NIXDORF Keyboard/Display Used in CWDS.

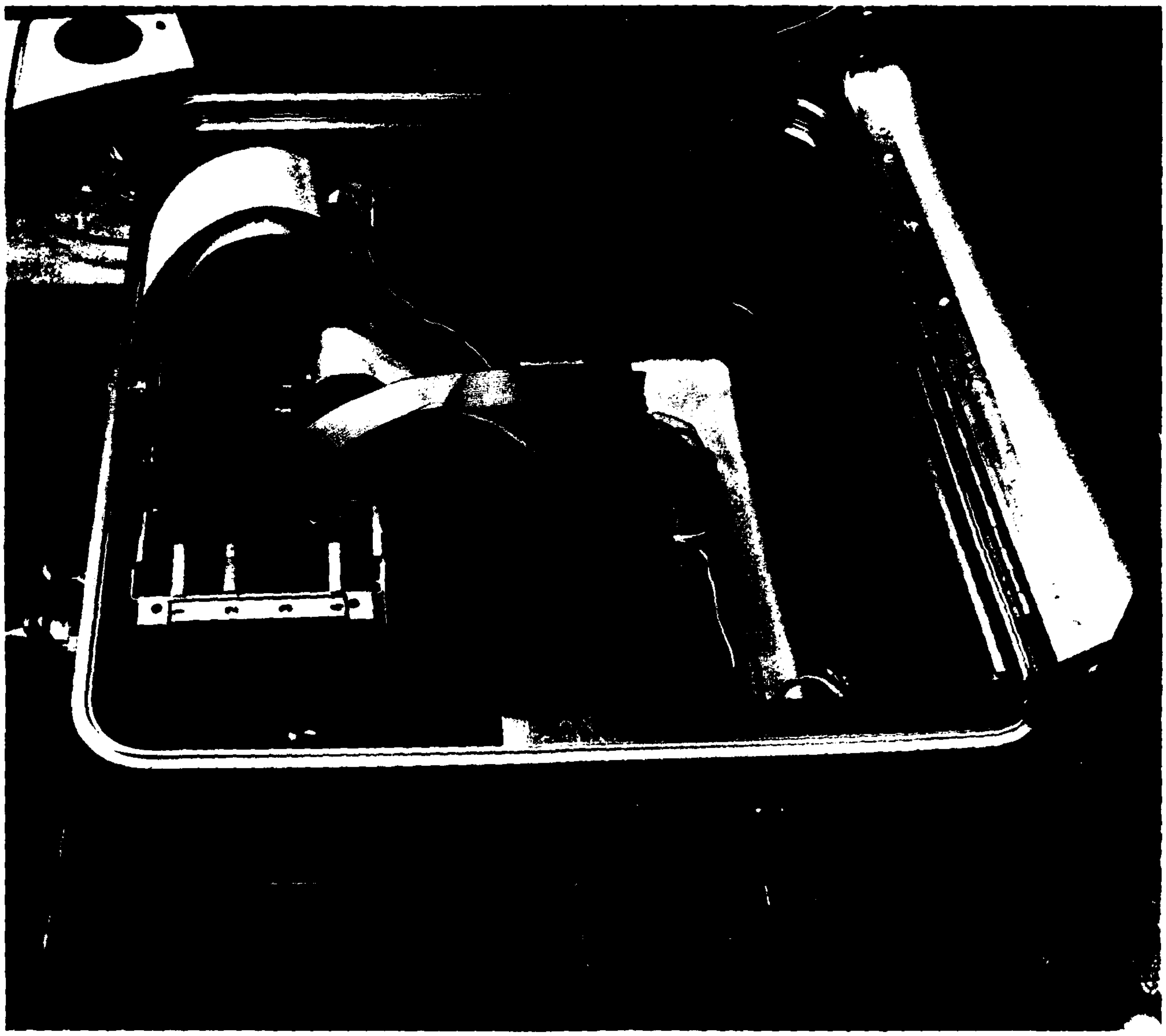

Figure 2. Box Containing Processor and Dedicated Receiver for the CWDS.

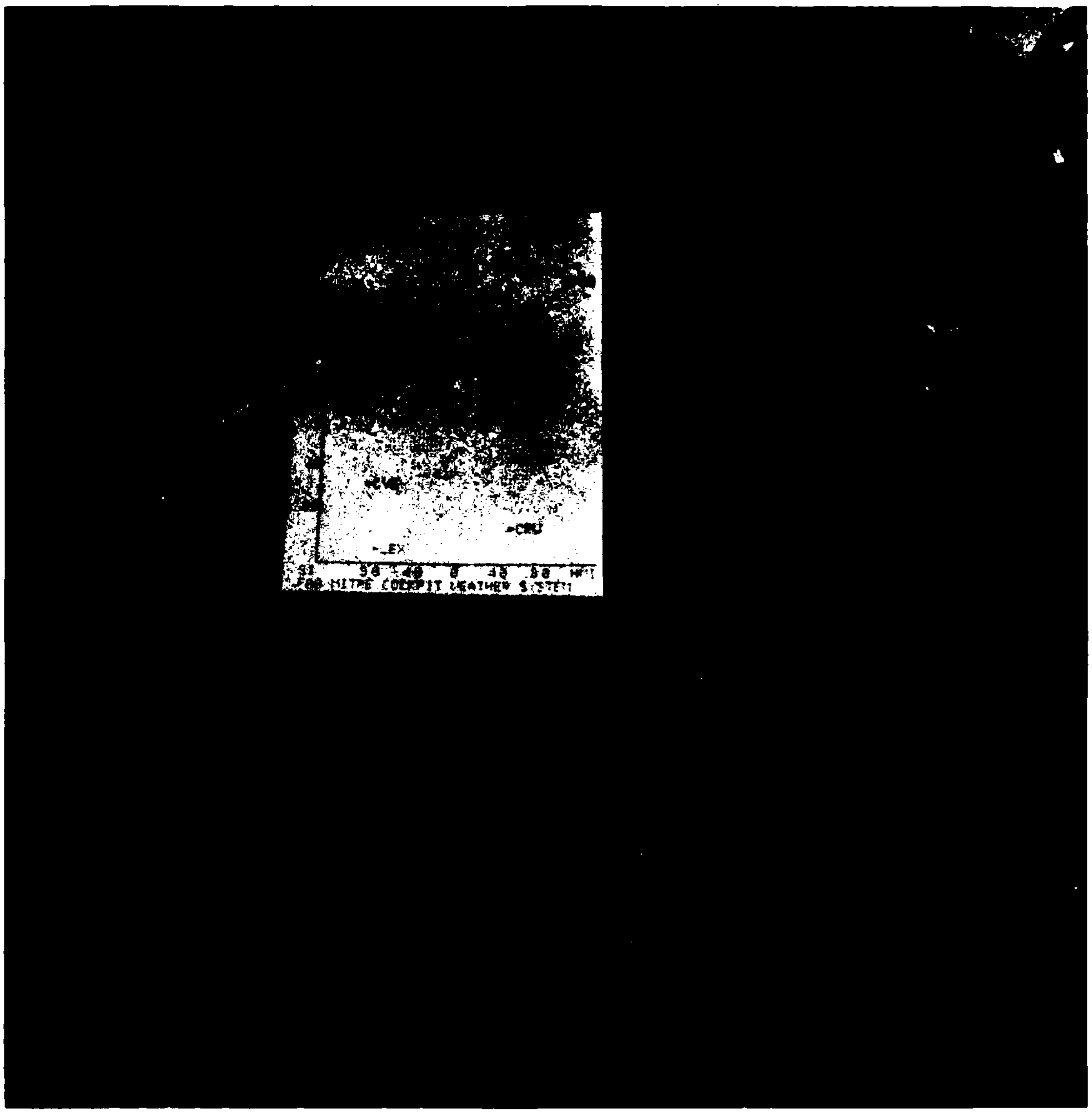

Figure 3. Dot-matrix Printer Manufactured by Alphacom.

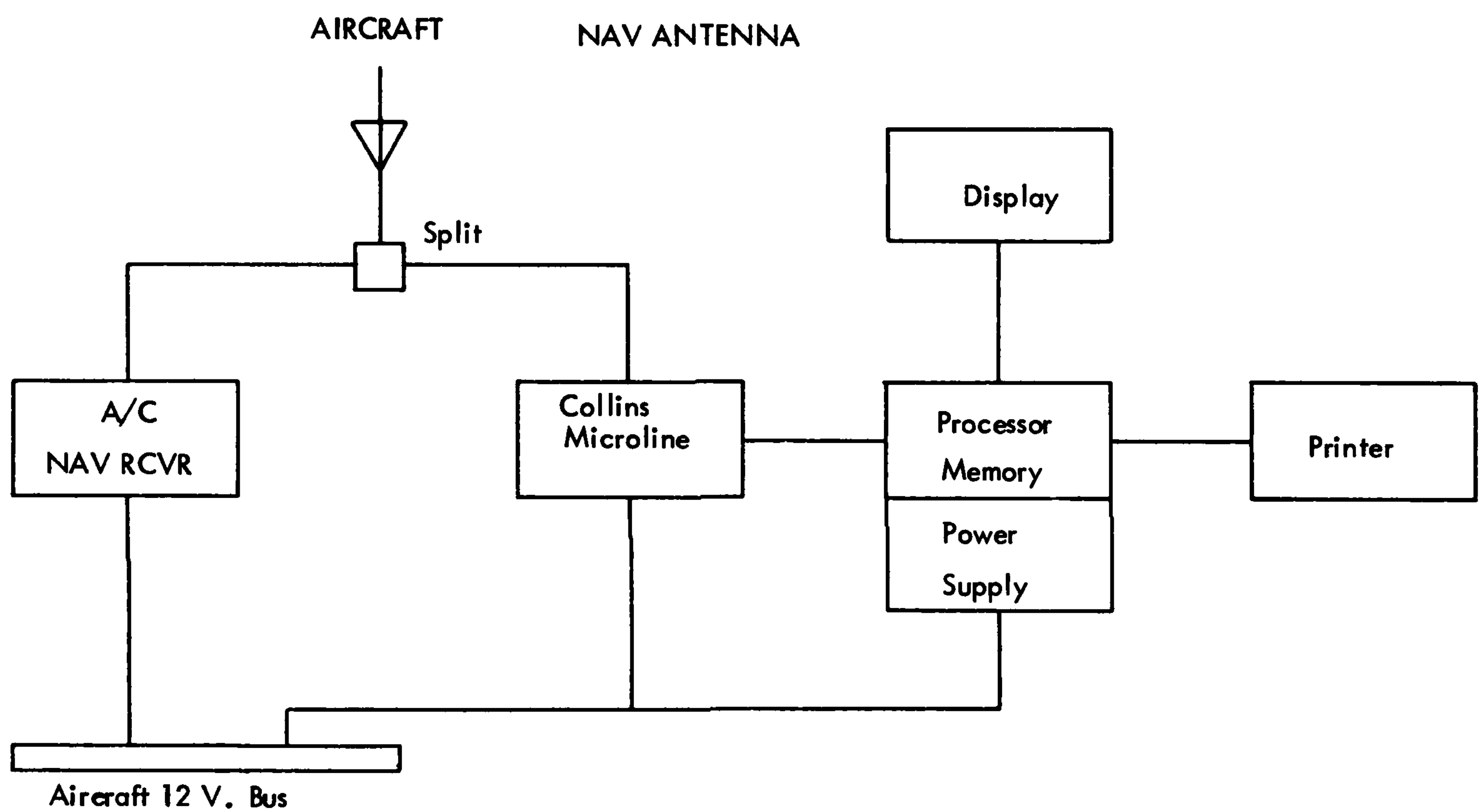

Figure 4. Block Diagram of CWDS.

IV. THE FLIGHT PLAN

A route was planned which involved airspace that was covered by the three VORs that had been selected for uplinking of the weather information. The Rosewood VOR (ROD), The Appleton VOR (APE), and the Zanesville VOR (ZZV) are nearly on a straight line west/east through central Ohio. See Figure 5. These are conventional VORTAC-type stations owned and operated by the FAA.

There were two principal considerations used when selecting the three particular VORs for this evaluation. Zanesville was in place from the previous study and required no additional effort to make it usable. The capability to connect Rosewood and Appleton came relatively easily, in part, because of the previous coordination with FAA Great Lakes Region. Second, typical weather movement could be expected to be from west to east along this line, thus allowing for greater time to explore the dynamics of the weather system as seen on the CWDS in the cockpit.

Constraints accepted were limitations on coverage area in the north-south direction, close proximity to the northern boundary of the Indianapolis Air Route Traffic Control Center, and some coverage area being included in restricted area 5503.

The particular route selected is shown in Figure 6 and is a closed loop starting west out of the home base, Ohio University (UNI) then proceeding to the Circleville NDB, to the Clark County NDB (CCJ), to Rosewood VOR (ROD), to Tiverton VOR (TVT), to Newcomerstown (CTW), to Parkersburg (PKB), and finally return to Ohio Univeristy (UNI). The total length of the route is 321 nm. Navigation fixes used were both NDB's and VOR's because by involving NDB's it is possible to obtain a qualitative assessment of effects of lightning discharge activity on the navigation and how it affected performance of the uplink.

The route is of sufficient length to allow for changes in the weather patterns during the approximate two-hour duration that is required by the aircraft for the circuit. The intent, also in the design of the route, was to allow for and encourage, the pilot to take short cuts based on the weather patterns received. The plan was to fly a route that gave the most demonstrable evidence that the uplinked weather was either useful or not useful to safe conduct of the flight. Evidence was desired as to the additional value provided over the voice information that was received via the FSS on the voice channels available to all pilots.

Altitudes planned ranged from 6000 to 12,000 feet. Altitudes of at least 6000 feet were required for good VOR reception throughout the circuit. Higher altitudes would, at times, be desirable in order to get above the summer haze to permit visual contact with cumulonimbus clouds and thus allow for correlations with uplinked weather patterns.

Weather sequence from Cincinnati, Dayton, Columbus, Findlay, Zanesville and Mansfield were programmed by MITRE for the uplink, and these were some of the most useful for flights over central Ohio.

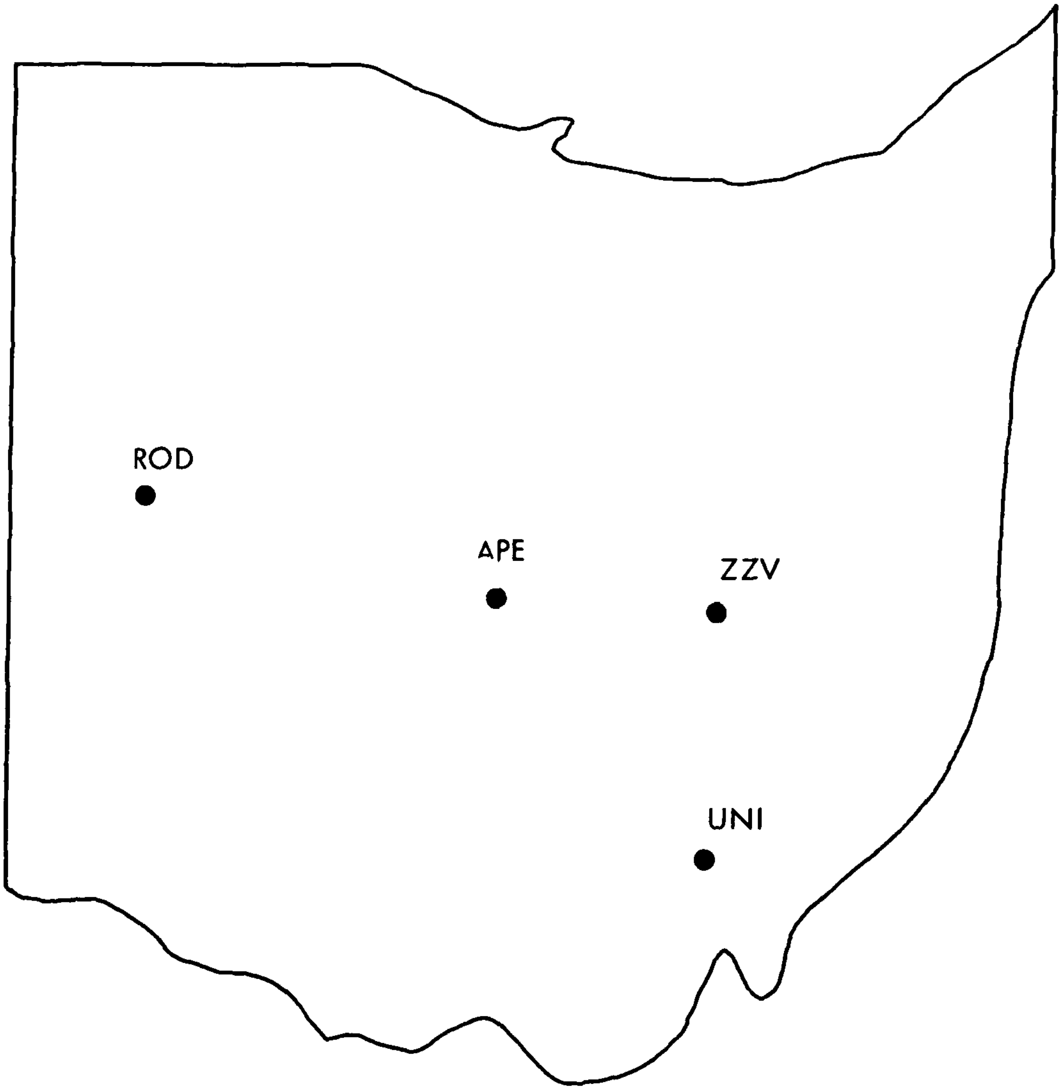

Figure 5. The Route Selected for Uplinking of the Weather Information Through Central Ohio Included ROD, APE, and ZZV.

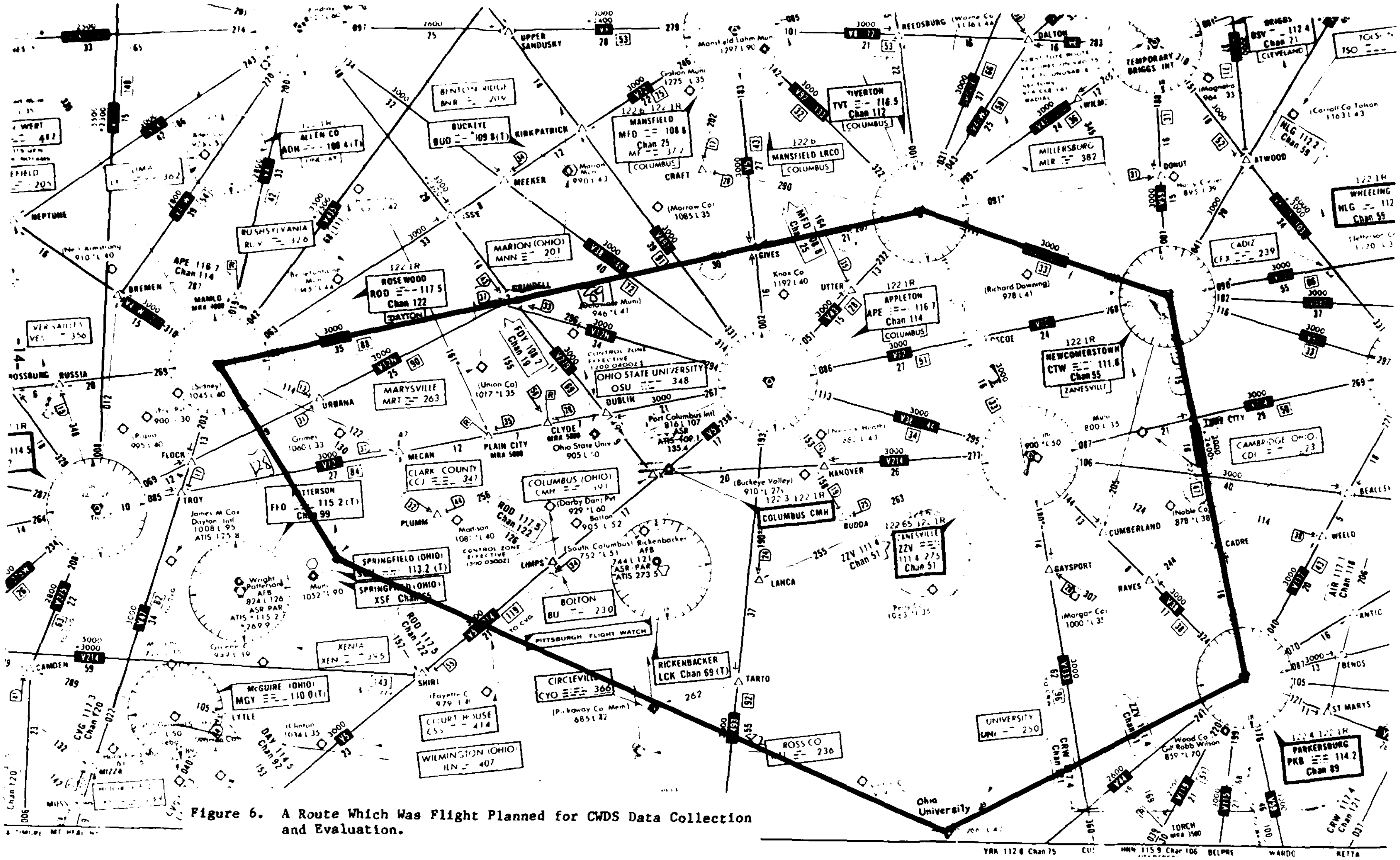

Figure 6. A Route Which Was Flight Planned for CWDS Data Collection and Evaluation.

Typically, a well-defined squall line enters Ohio on a north, northeast-south, southwest orientation and proceeds across the state in 6 to 8 hours. During that time there are, of course, diurnal effects that work to change the character of the system. A line passing a point in the afternoon can be expected to produce much more severe weather than one passing in the morning. A fast-moving line, for example, will likely produce more intense storms while a more difuse system will give more moderate shower activity.

Ideally for this work, extensive operations with fast-moving systems were desired. Unfortunately, during this evaluation program the summer of 1982 did not produce a great number of sharp, fast moving weather systems. On one occasion, it became possible to initiate a flight that penetrated the line and was able to operate on the west side in the late afternoon such that good visual opportunities were available with the intense low-angle sunlight. The results are given with the discussion of the September 15, 1982 data set.

More common was the presence of a wide-spread area of rain showers, most of level 1 with some level 2, and on occasion a level 3 or 4 being present. Several flights were initiated with these conditions and the results, of course, were less spectacular. This was due, in part, to more prevalent IMC (instrument meteorological conditions) with the slower moving or stationary systems. It is particularly noteworthy that one of the most dramatic uses of the CWDS is when a pilot has received a briefing by phone prior to flight that there are rain showers or thunderstorms in the area but has not been able to obtain a precise picture of these because of the limitations of voice on the telephone. The pilot then proceeds to take off, many times penetrating IMC and climbs to an altitude where he can begin acquiring the CWDS data. The first picture he receives is indeed a revelation. It is truly worth a thousand words and more. From his cockpit in IMC, he now has definitive information as to whether the heading he is now on is a good one for avoidance of the heavy weather or, if not, what is a preferred heading to minimize encounters with adverse weather.

It is not easy to convey, especially to a lay reader, the profound importance of having graphics information available for that decision making. From a situation of having to remember a telephone conversation relating less than current data provided by a flight service station specialist, to one where the graphics are there in front of the pilot is, indeed, a dramatic step forward in the process of providing the pilot with critical decision-making information in the cockpit.

V. FLIGHT ACTIVITY

There were 21 flights conducted during the time period of May to September 1982 for the express purpose of evaluating the capability and performance of the cockpit weather dissemination system. Nine of these flights produced usable information with respect to performance. Five flights were for checking operation of equipment preparatory to collecting weather data. During four flights equipment failure was experienced and six flights had, as one purpose, at least the demonstration of performance to concerned observers. Identification of these observers is given in the Appendix A.

Three flights have been selected for detailed discussion. The first was an early flight in the program during which the use of the CWDS clearly provided the pilot with help in successfully completing a specific flight. This is the first known example of a flight operation successfully using an automatic uplink of weather to execute a route and proceed to a destination successfully without undesirable consequences of penetrating heavy weather. This particular flight approached an area of thunderstorms which contained the destination airport. The second flight during the peak of the thunderstorm season involved, again, the completion of a flight whose destination was also the Ohio University airport. Heavy weather blocked what would have been the usual route. Successful avoidance of the severe weather was accomplished and an easy flight resulted. Finally, for a good example of weather identification and correlation of visual observations with uplinked data, the results of the September 15 flight are selected. The significant weather was occurring in two areas both north and south of the Ohio University airport. The flight proceeded to the west and was able to get above the haze and sufficiently far enough to the west of the cells that excellent lighting and visibility were available to make good visual observations and obtain some photo documentation.

A. Example: Use of CWDS to complete cross-country flight into Ohio University Airport on May 20, 1982

During the 30-hour period beginning at 1800 EDT on May 19, 1982, a moist, unstable air mass persisted over most of Ohio, western Pennsylvania and western West Virginia. Thunderstorms were present throughout this area beginning at 1800 EDT on the 19th and continuing on until after the flight terminated at 1925 EDT on May 20, 1982. The flight had departed the Ohio University airport at 0700 EDT on May 20, 1982 enroute to Washington, D.C. A thunderstorm cell was just west of the airport for takeoff and served as a harbinger of what could be expected on the return trip.

The return flight departed Washington National Airport at 1710 EDT (2110 GMT) and proceeded at 8000 feet along a route directly to Martinsburg then via Victor Airway 44 over Morgantown to a point aproximately 30 miles west of Morgantown. The intention was to continue along V44 to Parkersburg directly to Ohio University.

Weather information obtained by voice from Pittsburgh Flight Watch (EFAWS) indicated that level 3 and 4 rain areas were present on V44 30

miles west of Morgantown and westward beyond Ohio University. The flight was entering IMC and there was concern as to what alternatives existed for the routing. The weather data was not being received at this time on the CWDS. An inquiry was made to the Clarksburg Approach control concerning the weather they were observing. The response was that, from their indications, a deviation to the south of V44 would be the best that they could suggest. They indicated that they could not provide any specifics concerning the intensity. This deviation was begun at 1835 EDT (2235 GMT). Flight conditions were multilayered clouds, towering cumulus imbedded in haze, occasional light rain and light turbulence.

A few minutes after the flight began the deviation from V44, the lock on the weather data stream coming from the Zanesville VOR was obtained as evidenced from the LED display on the keyboard unit reading CMH radar data. Figure 7 shows the route and the deviation which was accomplished. Subsequent Figures 8 to 18 show a sequence of radar reflectivity patterns which were uplinked and received by the aircraft in flight.

Although decision making was underway prior to lock on the Zanesville VOR and uplink of the data, the discouraging information received from the Pittsburgh Flight Watch and the uncertainty of the Clarksburg approach controller in giving information concerning further routing meant that additional relevant data was vital. It was fortuitous that the lock occurred at that precise time because with a picture of the weather areas ahead to the destination the decision on the routing became quite simple. The flight progressed comfortably along a path south of Parkersburg westbound to Ohio University airport (UNI). Flight conditions were 50 percent IMC with no visibilities greater than two miles even outside the clouds. The haze layer extended well above 8000 feet thus making it impossible to view conditions other than those that were immediately ahead. Certainly, the visibilities when outside the clouds were not great enough to permit route adjustments other than what might be abrupt and resulting in concern to passengers.

Evidence of the severity of the thunderstorm activity in the Parkersburg area was the outage of the communications link caused by lightning. Loss of communications with some aircraft in the airspace eventually caused a delay in receiving the approach clearance at UNI. Concern for deteriorating conditions suggested by the weather radar picture that was being received indicating rain areas to the west of UNI prompted ultimate cancellation and a VFR descent and landing. When on the ramp at UNI, the rain areas did arrive at the airport, although they were not sufficiently intense to have caused major problems in a landing.

The lockon came at a 68 nm range at 8000 feet. At this point, in spite of the long range from the Columbus NWS radar (115 nm), excellent information concerning the reflectivity patterns for the route area was obtained. This information, as can be seen from the figures, clearly indicated the corridor-type area which led from the location of the aircraft to the destination airport. Flight in this corridor was uneventful except for the haze condition.

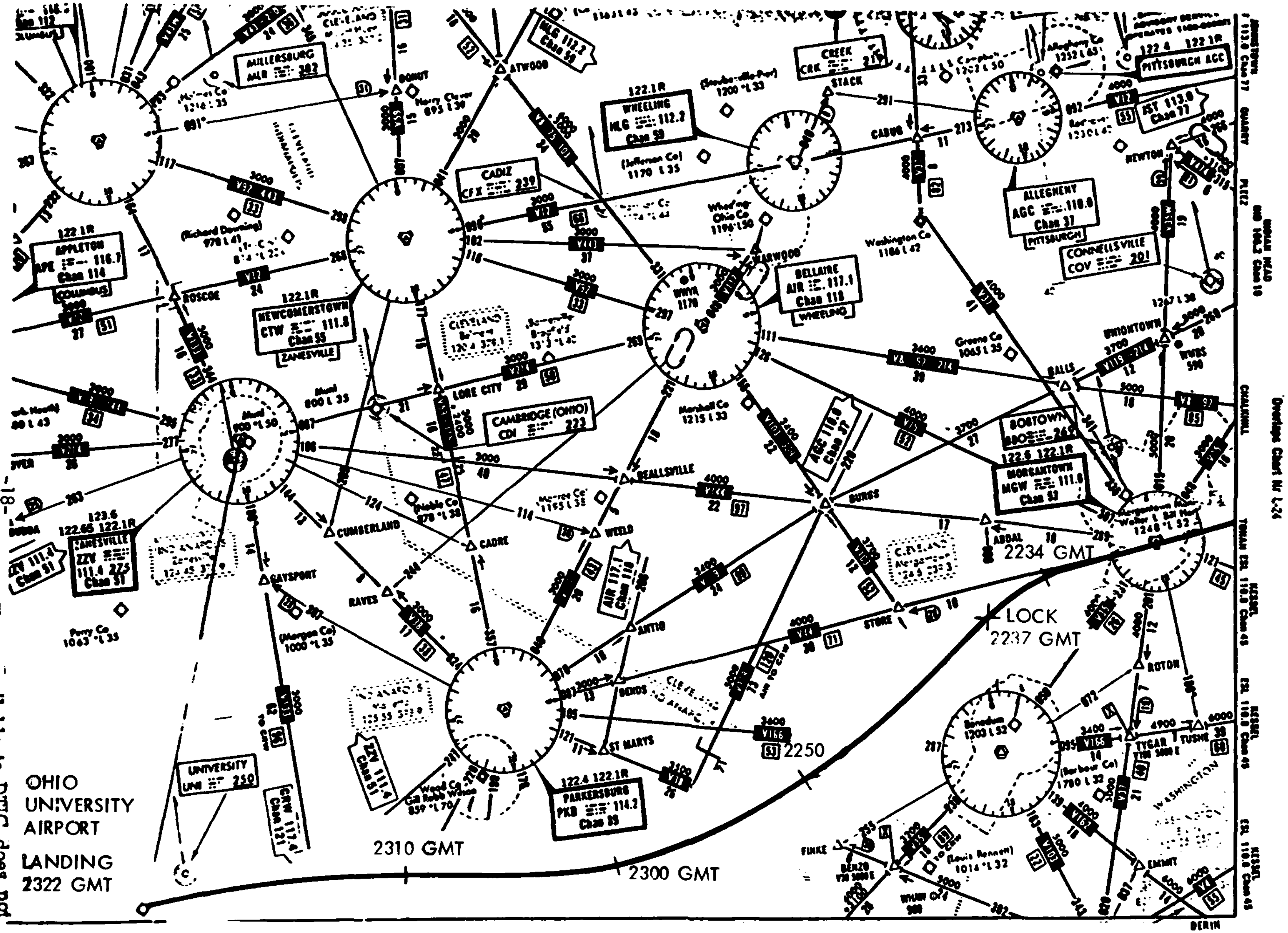

Figure 7. Flight Route and Track Accomplished to Avoid Adverse Weather Displayed on CWDS on May 20, 1982.

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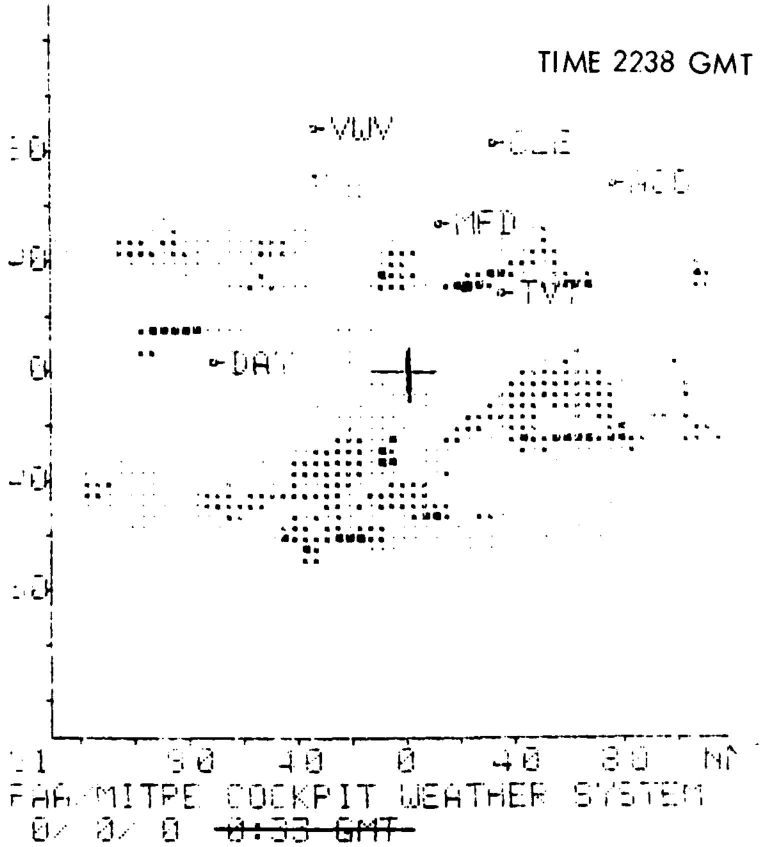

Figure 8. Initial call-up with 256 nm scale and Columbus at the center. There is good indication that the Parkersburg area to the SE has considerable weather. Incomplete picture. This and following figures are direct copies of the printouts from the dot-matrix printer. Level 1, 2 and 3 radar returns are visible.

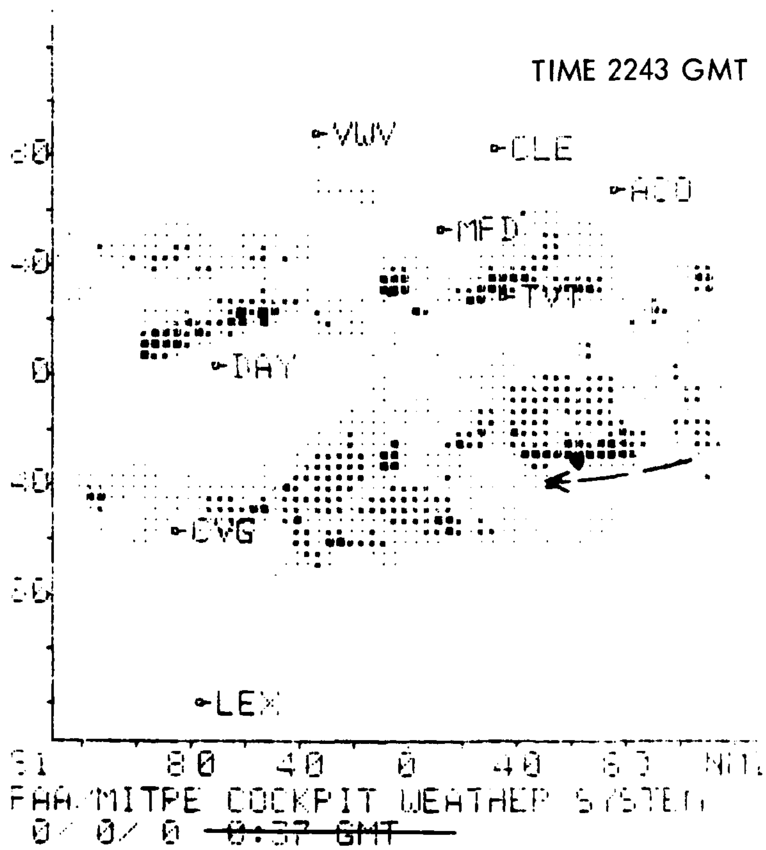

Figure 9. Repeat 5 minutes later with complete picture.

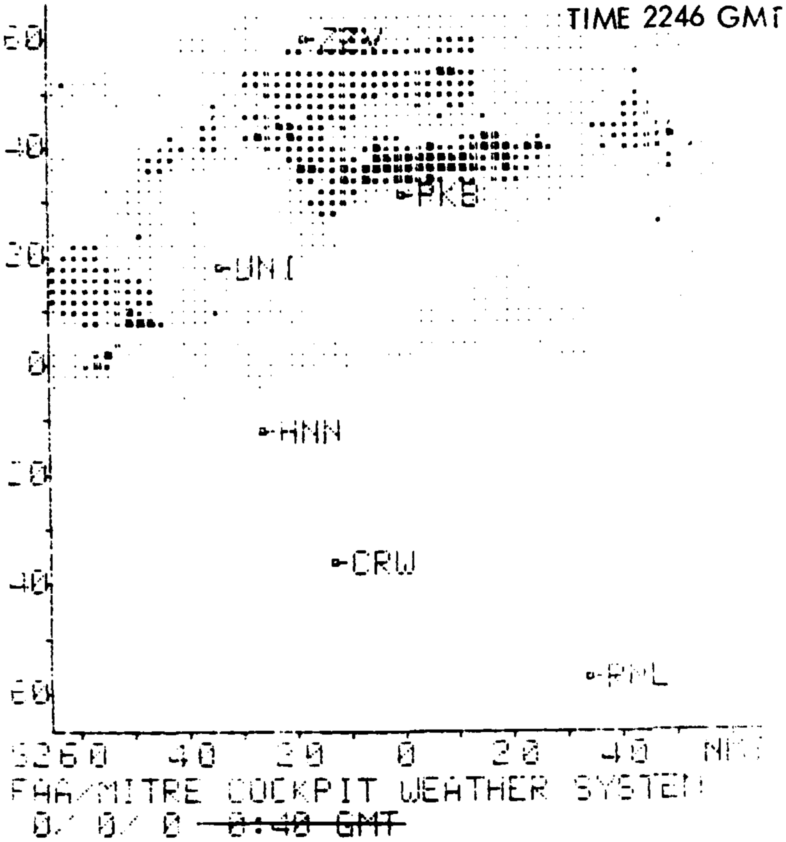

Figure 10. Acquired using the SE quadrant call-up. Here is the first clear indication of what weather could be expected along the route and this offered good evidence that skirting south of Parkersburg to UNI would keep the flight clear of heavy weather. Note was made that there was weather just west of UNI and this suggested that delays would likely furnish worsening weather for landing at UNI since the weather was reported moving from W to E.

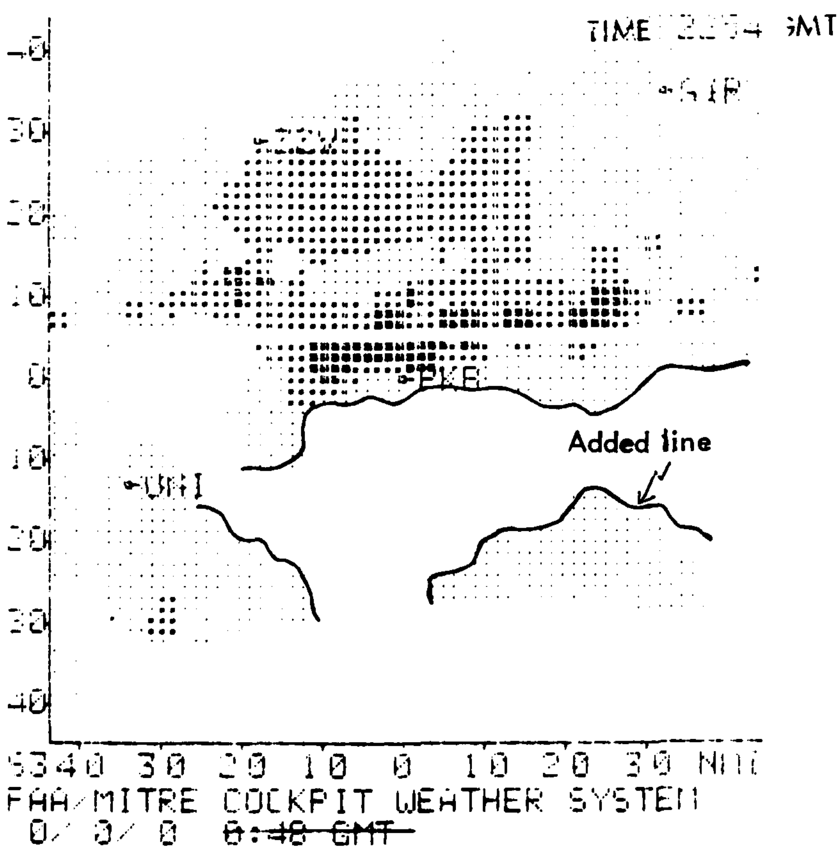

Figure 11. Repeat with less dropout. At this point the area most desirable for the flight to take is discernable south of PKB to UNI. Lines added on map to enhance open area.

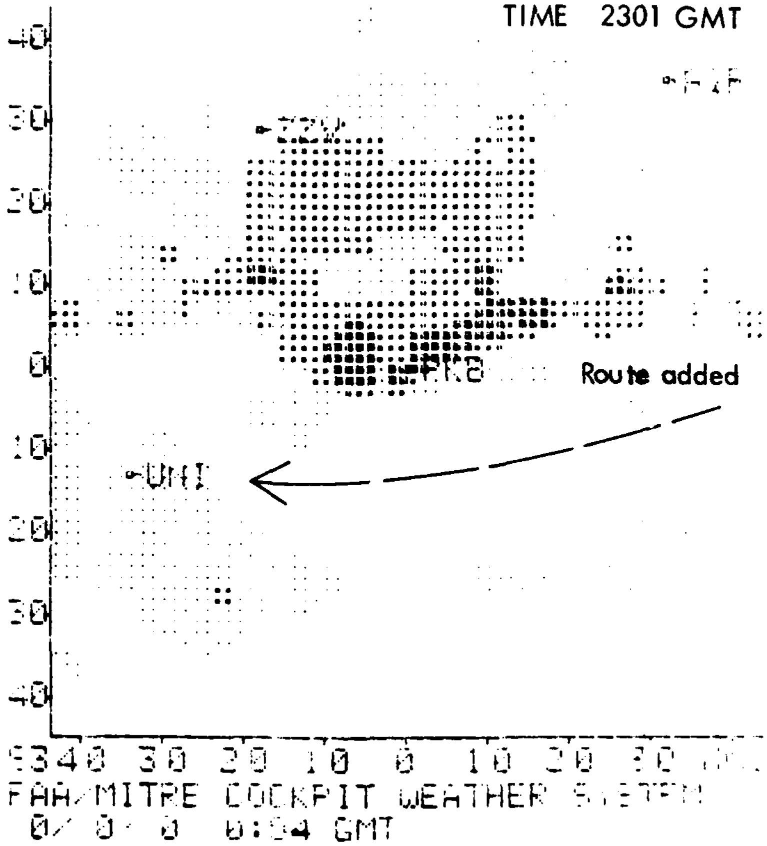

Figure 12. Recentered on PKB with a 3 scale. Good complete picture at this point in time was important because the flight was in IMC at 8000 feet.

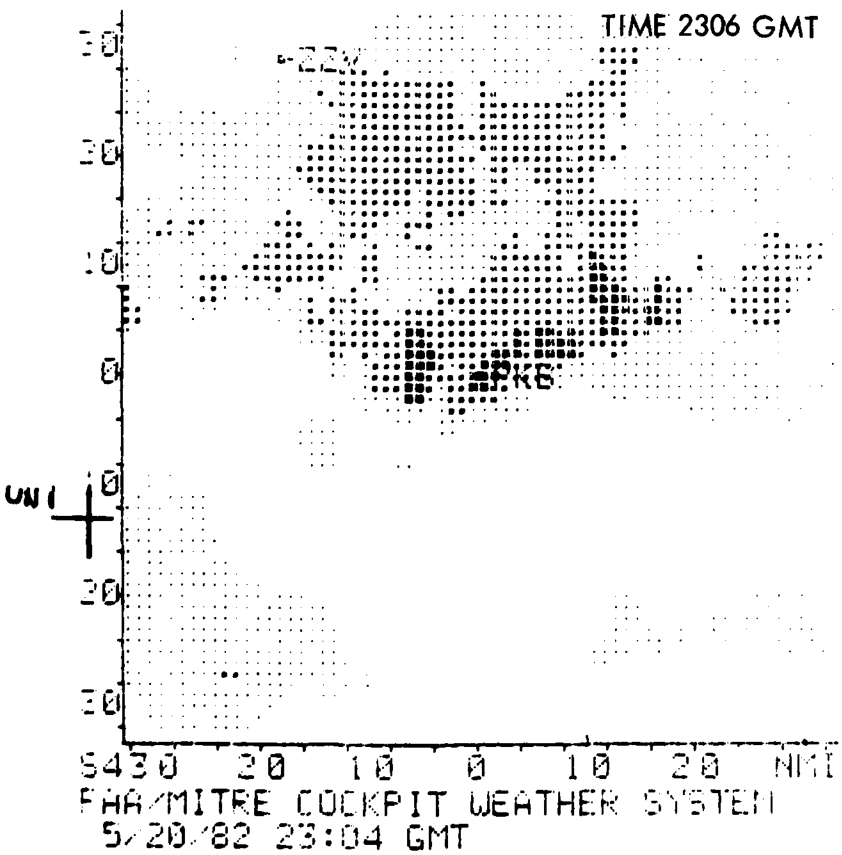

Figure 13. Rescaled to 4 but this did not quite move UNI onto the map area Experience would of course tell one more about what scales to use where.

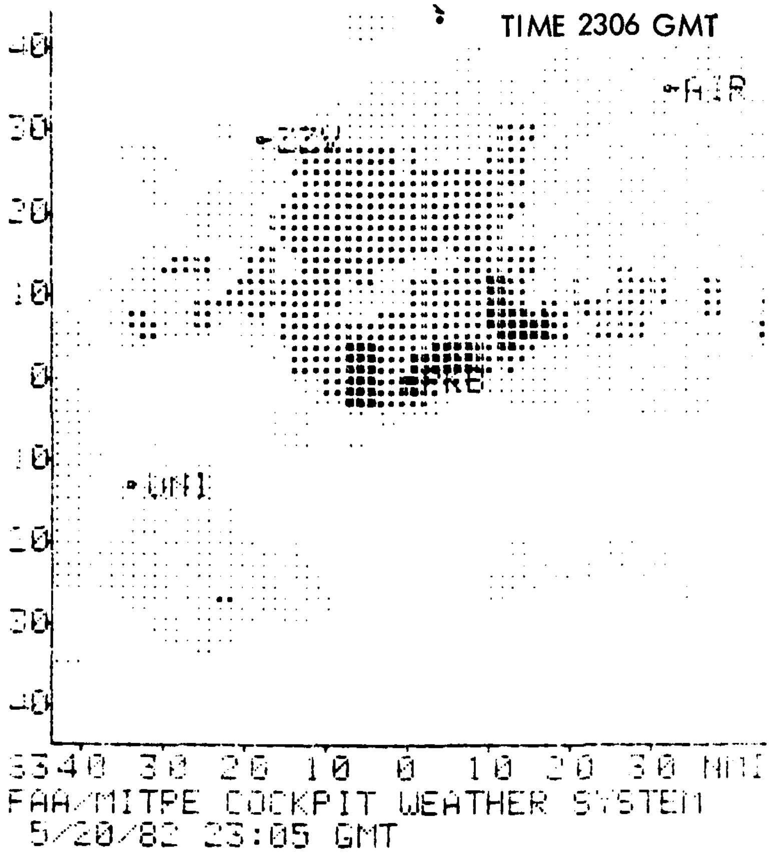

Figure 14. Rescaled to 3 which brought UNI onto the map. It is probable that the area 30 miles southeast of PKB is greater than the level 1 indicated. Clarksburg approach control indicated a heavy area of precipitation to the south of the flight track and observations in flight indicated buildups in the area. Because this is over 100 miles from the radar site there is opportunity for under-rating the intensity especially since the storm over PKB would be attenuating the radar signal.

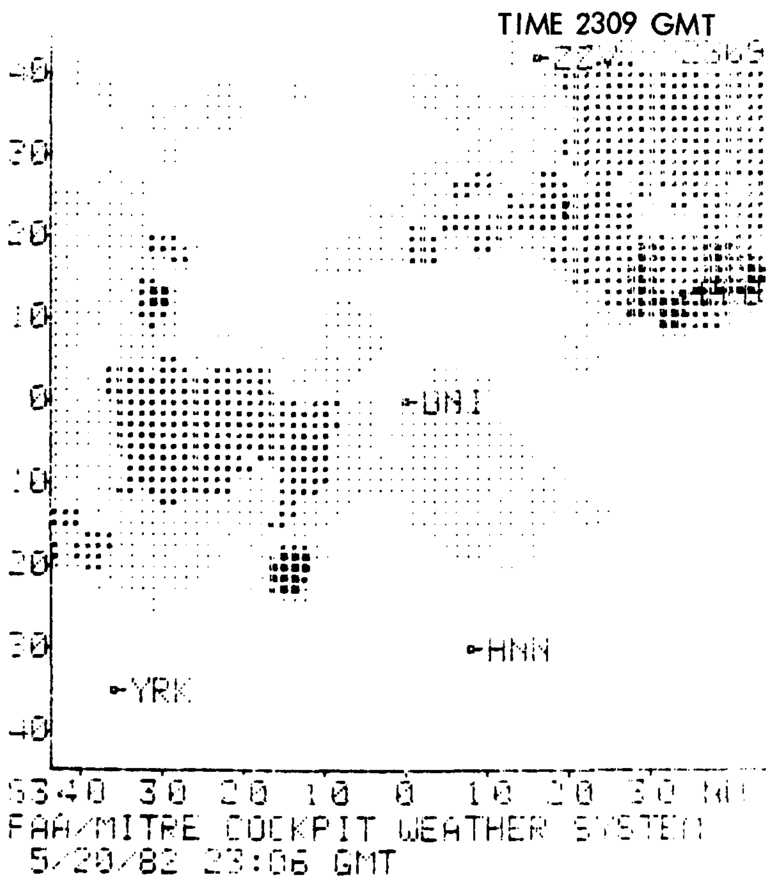

Figure 15. The picture was recentered on UNI because the flight was approaching its destination. The route coming from the east into UNI continued to look good; however, the level-two rain area west of UNI was a concern because the flight was given a 25-minute hold for the approach. Conflicting traffic below which had lost ATC contact because the remote transmitter site at PKB had suffered a lightning strike was given the priority.

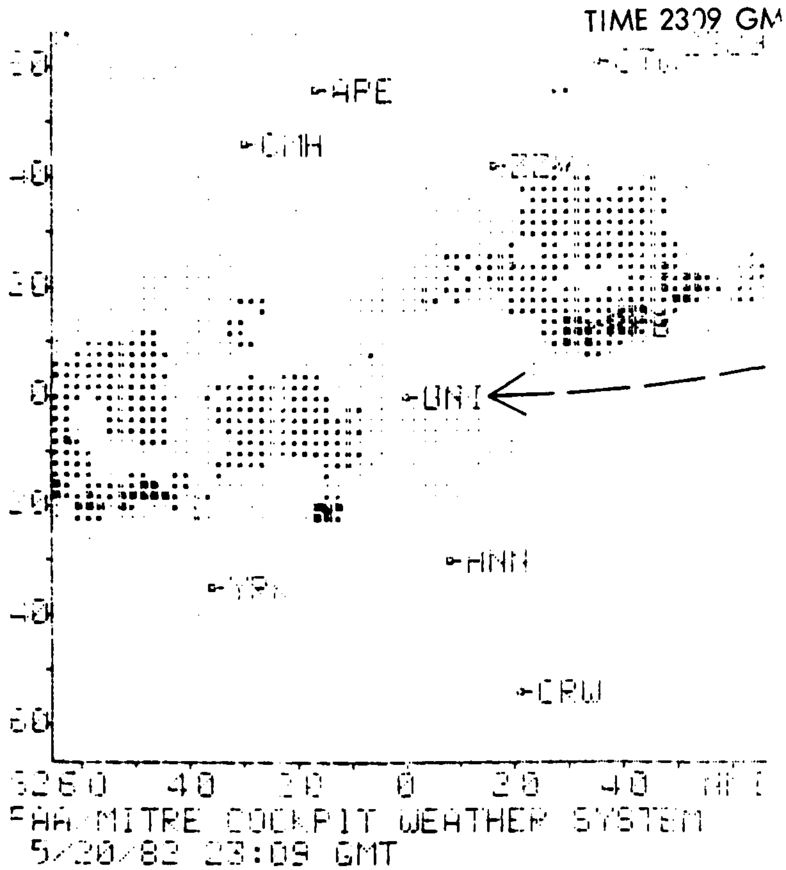

Figure 16. To obtain a synoptic view the scale was changed to 2. Clearly, the UNI airport is in a kind of pocket with the best approach fortunately being from the east. This was approximately 13 minutes before landing.

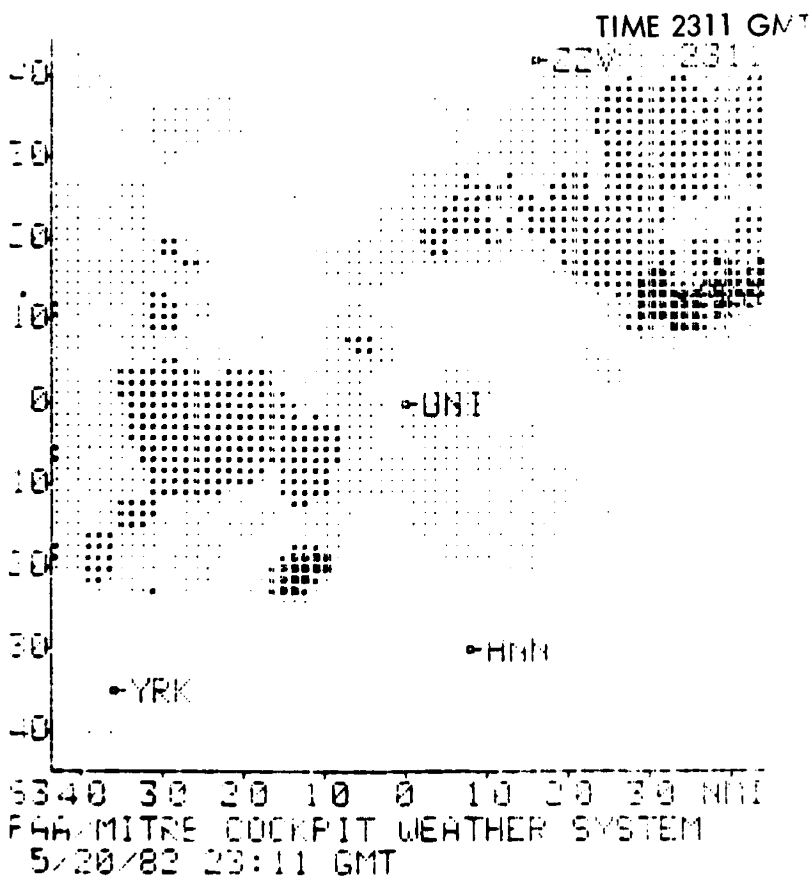

Figure 17. The scale was changed to 3 which was a good one for planning the final segment of the flight. This is 11 minutes before landing.

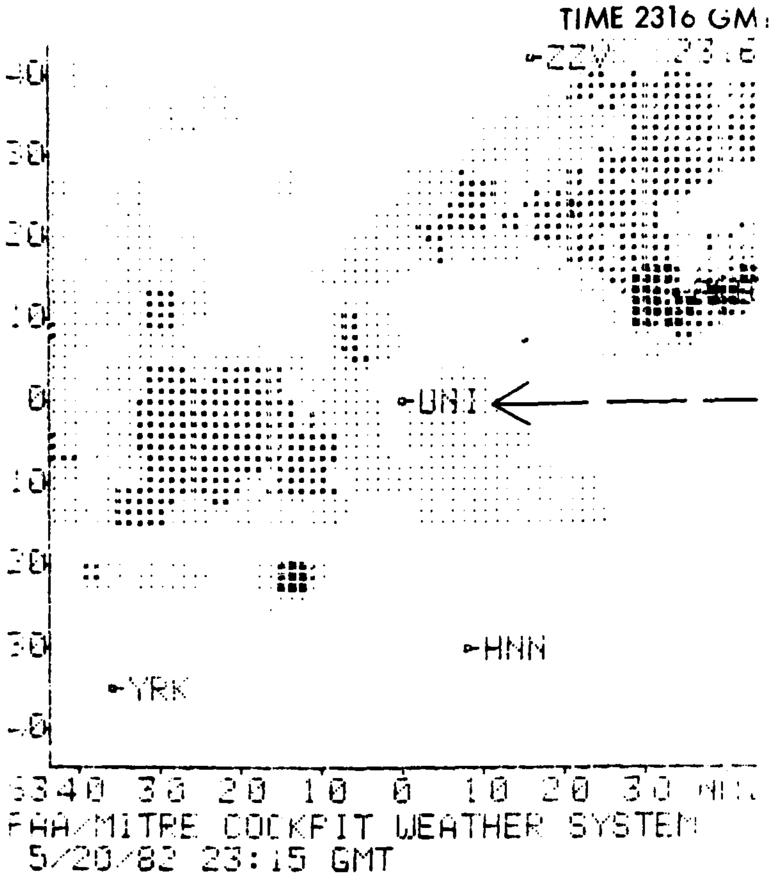

Figure 18. Final picture obtained 6 minutes before landing showed some rain for the approach but the area was not extensive. Actual conditions made possible a visual descent and cancelling of the IFR flight plan approximately 5 miles from the airport. While on the ramp after landing there was a brief period of rain but this passed and no further rain occurred at the airport for the next half hour.

Area navigation information was found to be useful in that it was the only practical way to position oneself on the weather radar data printout. The range/bearing from Parkersburg could be read directly and this would allow a reasonably quick denotation of position on the weather graphics display. This clearly points the way to one means of improving the usefulness of the display, i.e., including the RNAV information on the printer automatically. Captions on the figures elaborate on the details concerning flight along the alternate route selected.

B. Example: Application of CWDS for satisfactorily completing cross-country flight on July 19, 1982

Afternoon showers and thunderstorms were forecast for southeastern Ohio and western West Virginia for July 19, 1982. Outbound for Atlantic City, New Jersey at 0700 EDT the flight enountered only low overcast conditions; however, once out on top at 5000 feet it was possible to observe small cumulus evidence of some instability. On the return flight which departed Atlantic City at 1530 EDT (1930Z) only hazy conditions were noted; however, by the time of reaching Baltimore, significant cumulus were developing and this condition persisted along V44 continually as the flight progressed. When passing Baltimore, Washington Flight Watch reported a line of thunderstorms extending from Harrisburg, PA through Hagerstown, MD. southwestward to north of Martinsburg, WV. Martinsburg reported 4000 broken and 8000 overcast with a thunderstorm in progress. This buildup was visible ahead from the flight altitude of 8000 feet. After consultation with the Washington air traffic controller, the decision was made to deviate to the south of V44 to avoid the thunderstorm at Martinsburg. Only light rain and light turbulence were encountered.

The acquisition of information to make the decision for handling the Martinsburg weather required approximately 15 transmissions using three different frequencies. Keen competition for the ground personnel's time was evident since other pilots were also requiring information for their operations.

After approximately 150 miles of uneventful flight, the second area of weather was identified as being in the Parkersburg area and extending westward. Since Ohio University Airport is 42 miles west of Parkersburg, it became important to examine the weather conditions carefully because any substantial deviations could mean that the destination could not be achieved.

Information from both the Pittsburgh Flight Watch and Cleveland Air Route Traffic Control Center indicated a thunderstorm area could be expected near the Parkersburg VOR. Since this was directly on the route, as much information as possible was desired. Fortunately, prior to reaching the IMC and rain conditions, the lock was obtained on the Zanesville VOR data stream, and the first print of the Columbus weather radar return was obtained. This is shown in Figure 19. This somewhat synoptic view revealed the extensive areas of level 1 through 3 shower activity in southeastern Ohio. The scale was expanded and the coordinate center shifted to Parkersburg as shown in Figure 20. Visual indications from the cockpit,

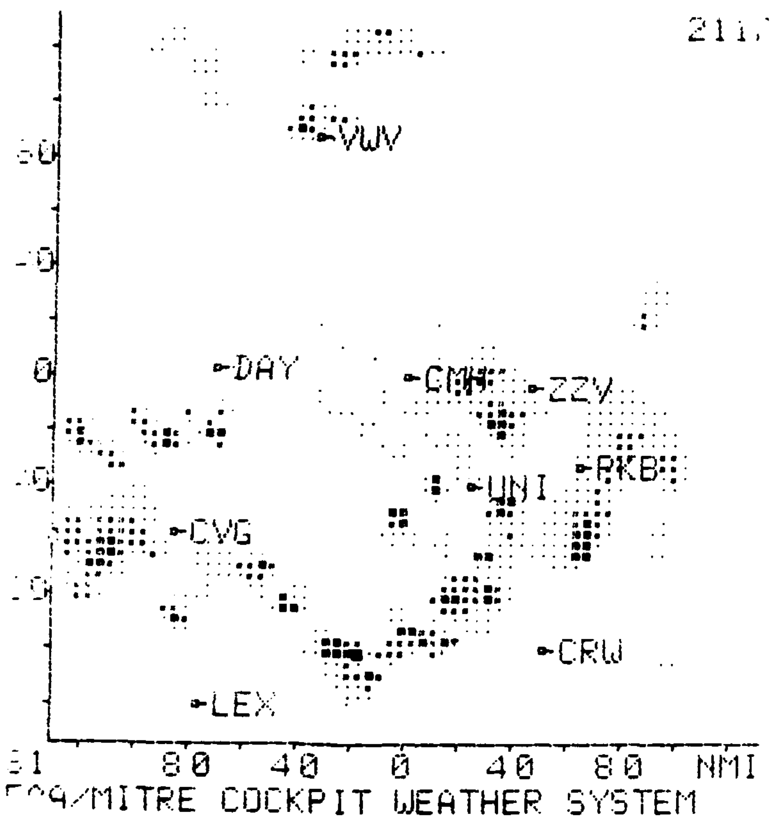

Figure 19. Initial Call-up of Weather Data on the CWDS.

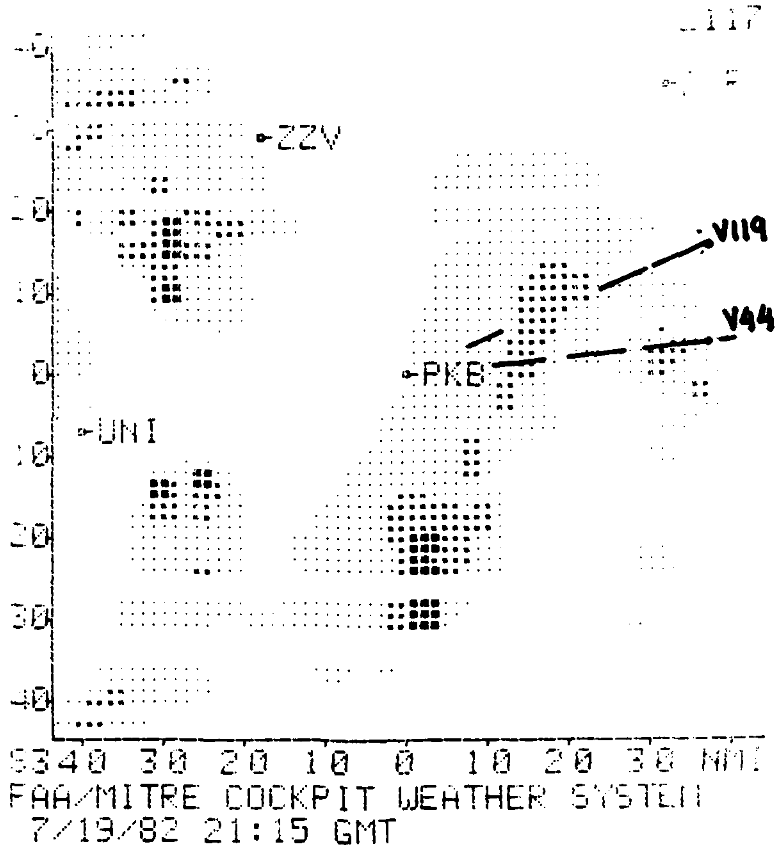

Figure 20. Printout with Scale Expanded and Coordinate Center Shifted to Parkersburg.

prior to entering IMC, revealed some tempting possibilities of deviations around the north side of Parkersburg. More ominous dark clouds were present straight ahead and to the south. Center recommended deviation north and their radar showed thunderstorm cells west of Parkersburg.

The light areas observed visually were evidently areas of light precipitation in contrast with heavier areas designated levels 2 and 3 by the radar. As the flight progressed on a northerly deviation approximately 8 miles north of the PKB VOR it encountered light rain and mild IMC. Figure 21 shows the CWDS depiction of the Columbus Weather radar with the coordinate center at the destination UNI. Quite evident is the open area free from detected rainfall return to the northeast of UNI extending to Parkersburg.

Approximately 5 miles northwest of the PKB VOR, the flight broke out of a light rain condition into the clear below a scattered variable broken deck of clouds with 10,000-foot bases. The visibility to the west was better than 10 miles. Cells were visible to the south and southwest and this correlated well with the CWDS picture.

One important advantage of having a printout rather than a cathode-tube display is the capability to identify trends. Two figures are selected to illustrate this, viz Figures 22 and 23. By comparing these, the reader will be able to detect the easterly movement of the weather in particular from just east of UNI. This was of particular interest because this was the destination of the flight. The area also diminished slightly in intensity. The area to the south of UNI, i.e., northwest of HNN (Henderson VOR) during this same time increased significantly in intensity. The time between the two weather radar pictures was only 11 minutes.

Once again nearly 15 radio contacts were made but this was due, principally, to the fact that this was an evaluation flight. Had this not been the case, as few as 5 contacts would have been sufficient. The capability to reduce radio channel congestion is clearly evident when the CWDS is used.

One interesting factor working against reduction of channel congestion at this time is the lack of information that is available at the Flight Service Stations, such as Parkersburg. In the cases when such evaluation flights were in progress, the FSS was interested in what was seen and, on at least one occasion, the information was passed along as a pilot report. In this and other similar cases, the CWDS aided not only the operators but other pilots who received the information on a relay, specifically, by means of pilot reports.

C. Example: Examination of correlation between visual and radar uplink observations - September 15, 1982

An outstanding opportunity to acquire data which would permit a correlation between visual impressions and the radar up-link picture produced by the CWDS occurred on September 15, 1982. A briefing given by the NWS personnel at Columbus indicated that there was considerable cell activity near

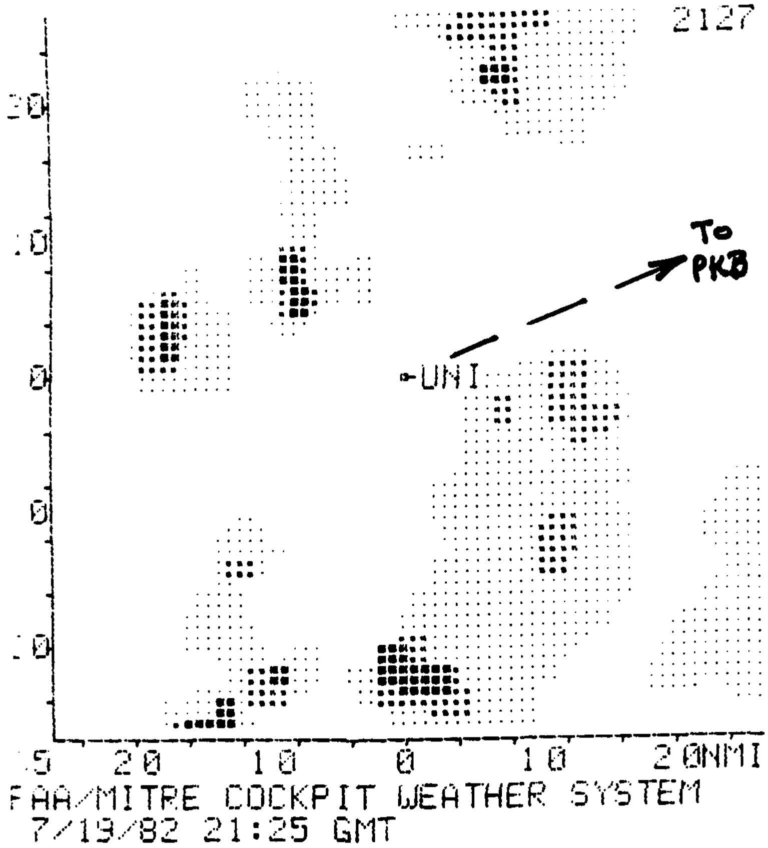

Figure 21. Printout With Coordinate Center Now At Destination Airport (UNI) And Scale of 5.

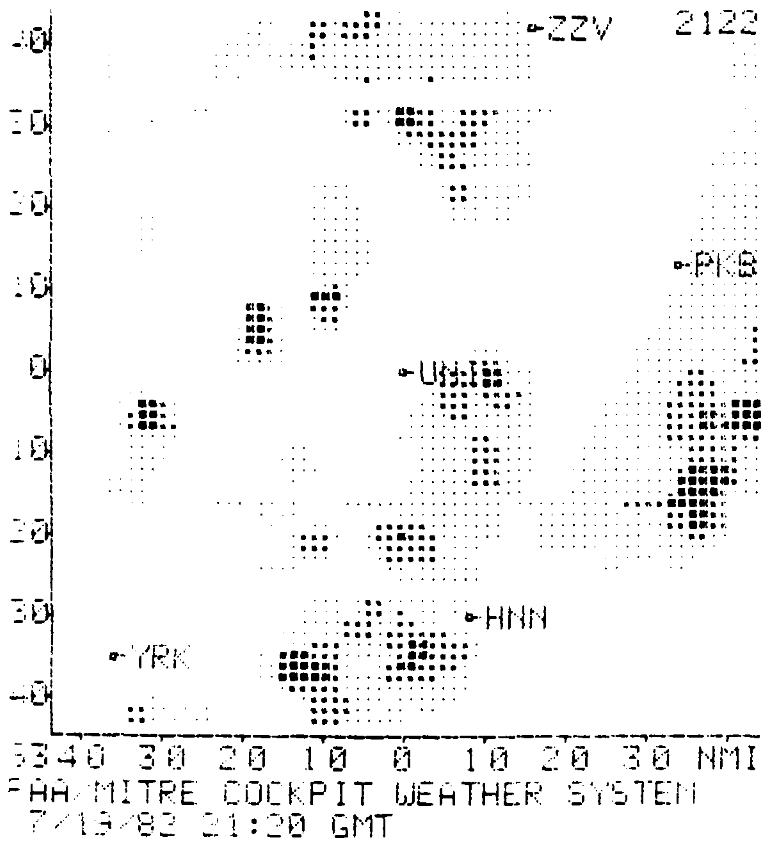

Figure 22. Printout Using a Scale of 3 Which Shows the Open Area to the North of A Parked PKB UNI Line.

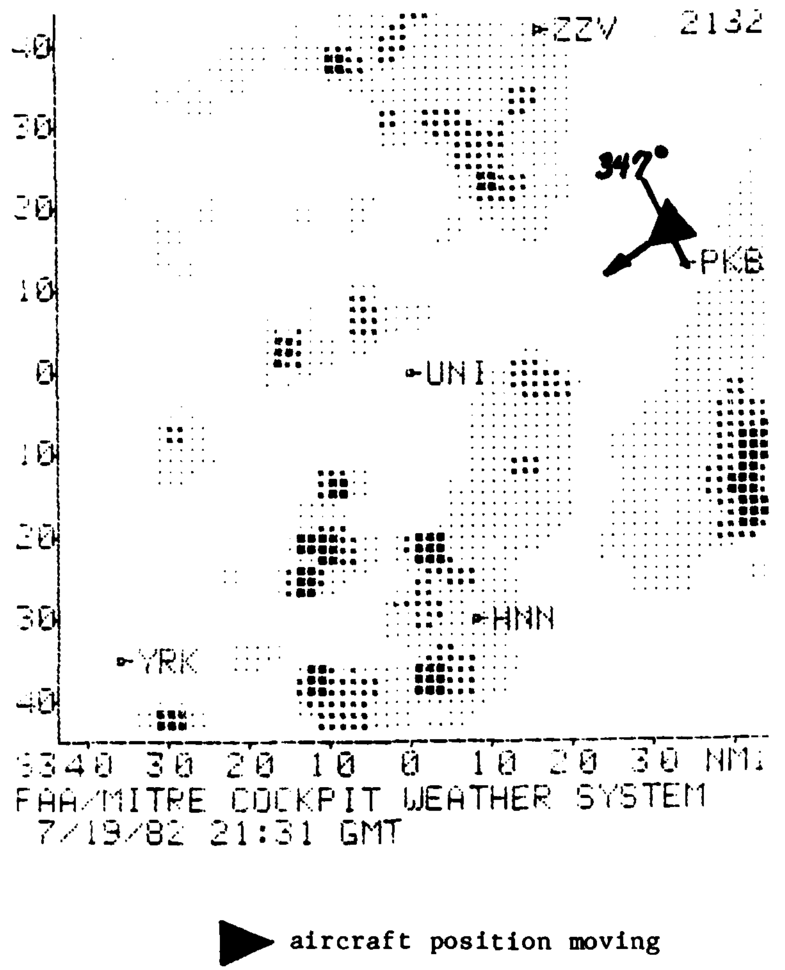

Figure 23. Printout of the Weather Approximately 10 Minutes Later Showing Eastward Movement.

Zanesville extending southward. Visual observations at the Ohio University airport revealed multilayered clouds with some cumulus and occasional light precipitation.

An IFR flight plan was filed for the standard route and departure was achieved at 1845 EDT (2245 GMT) with instruction to maintain runway heading, climb and maintain 6000 feet. This was accomplished in predominantly VMC; however, as the flight proceeded southwest bound, the flight penetrated some fractocumulus near 6000 feet. When clear of the clouds, visual observations revealed that to the west the tops of the major cumulus developments were quite low, on the order of 10,000 to 15,000 feet. To the south and southeast much higher tops could be seen. A Ryan Stormscope on board indicated there there were no returns from the cell areas to the south through west. All sferics acitivity was shown to be north of the Ohio University Airport.

The LED display indicated that the data storage began at approximately 3500 feet altitude and that by 4000 feet the storage was complete. The first printout was then obtained with a radar time notation of 2255 GMT. This is shown in Figure 24. Interestingly, the area south of the flight track southwestward from UNI shows up as level 2 activity which was not visually apparent due to the low tops or the lack of indication on the Stormscope.

Clearly, from the printout and consistent with the briefing, the major weather area possibly containing level 2 or 3 activity was southeast of Columbus in the area 10 to 20 miles southwest of Zanesville. After a southwest track duration of approximately 20 miles from UNI, Huntington Approach Control cleared the flight direct to the Circleville NDB and handed the flight to Columbus Approach Control.

After contact with Columbus Approach Control, request was made and approval obtained for a climb to 8000 feet with a turn direct to Appleton VOR. On the climb to 8000 the top of the haze was reached and flight visibility improved markedly. A photograph was made looking east and is shown in Figure 25. Clearly, this cloud formation is massive, and it was of sufficient interest that a closer look was desired. Accordingly, a request was made to proceed directly to Zanesville.

A review of additional radar pictures from the uplink indicated in Figure 26 that heavy weather would be placed between the flight and the destination airport UNI and this would be undesirable for practical purposes. Accordingly, a course was selected that would take the flight to the south of the weather mass. This was accomplished by selecting an area nav waypoint 180 degrees at 30 miles from the Zanesville VOR. One closer look at the weather directly ahead towards ZZV is given in the photo in Figure 27. A turn towards the waypoint presented the weather shown in the photograph contained in Figure 28. The southern edge of the major storm area is evident and the opportunity to stay on the edge appears to be a realistic one. The radar picture shown in Figure 29 reveals that the track to the waypoint should skirt the southern edge of the weather cell. Proceeding to the way point ZZV 180/30 gave a visual scene of moving

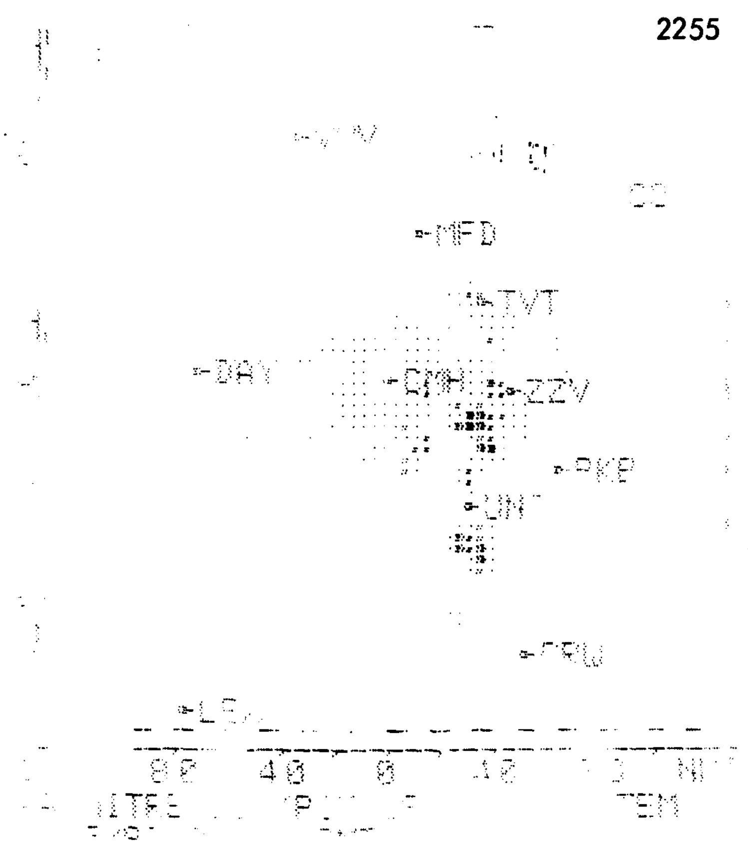

Figure 24. Initial Call-up of Radar Reflectivity Pattern Showing the Synoptic Picture.

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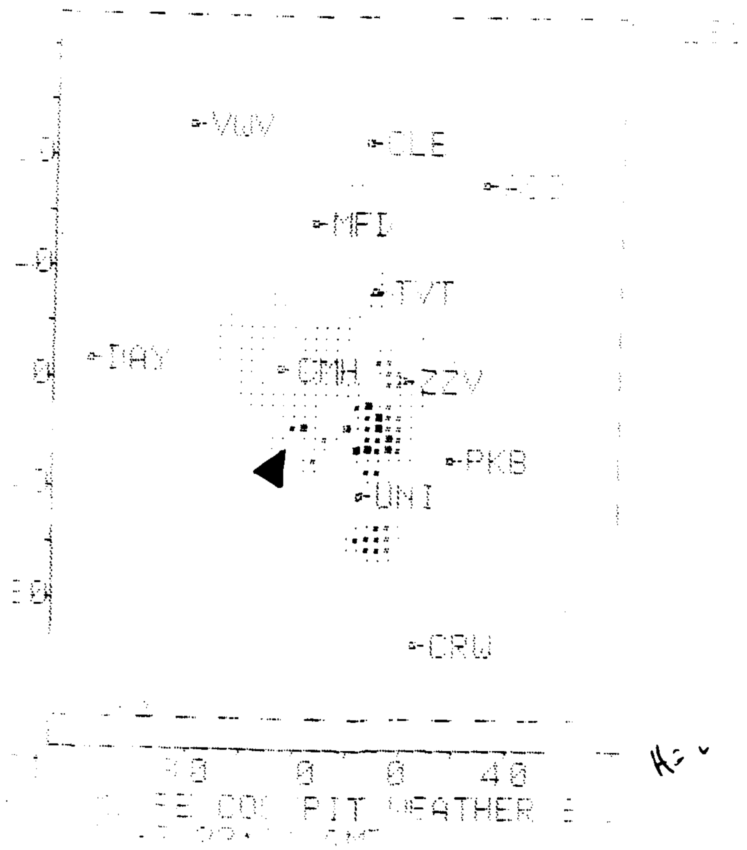
Figure 25. View of Cumulus Located Approximately 20 Miles South of ZZV.



aircraft position moving

Figure 26. Printout Indicating Levels 2 and 3 Patterns Between ZZV and UNI.

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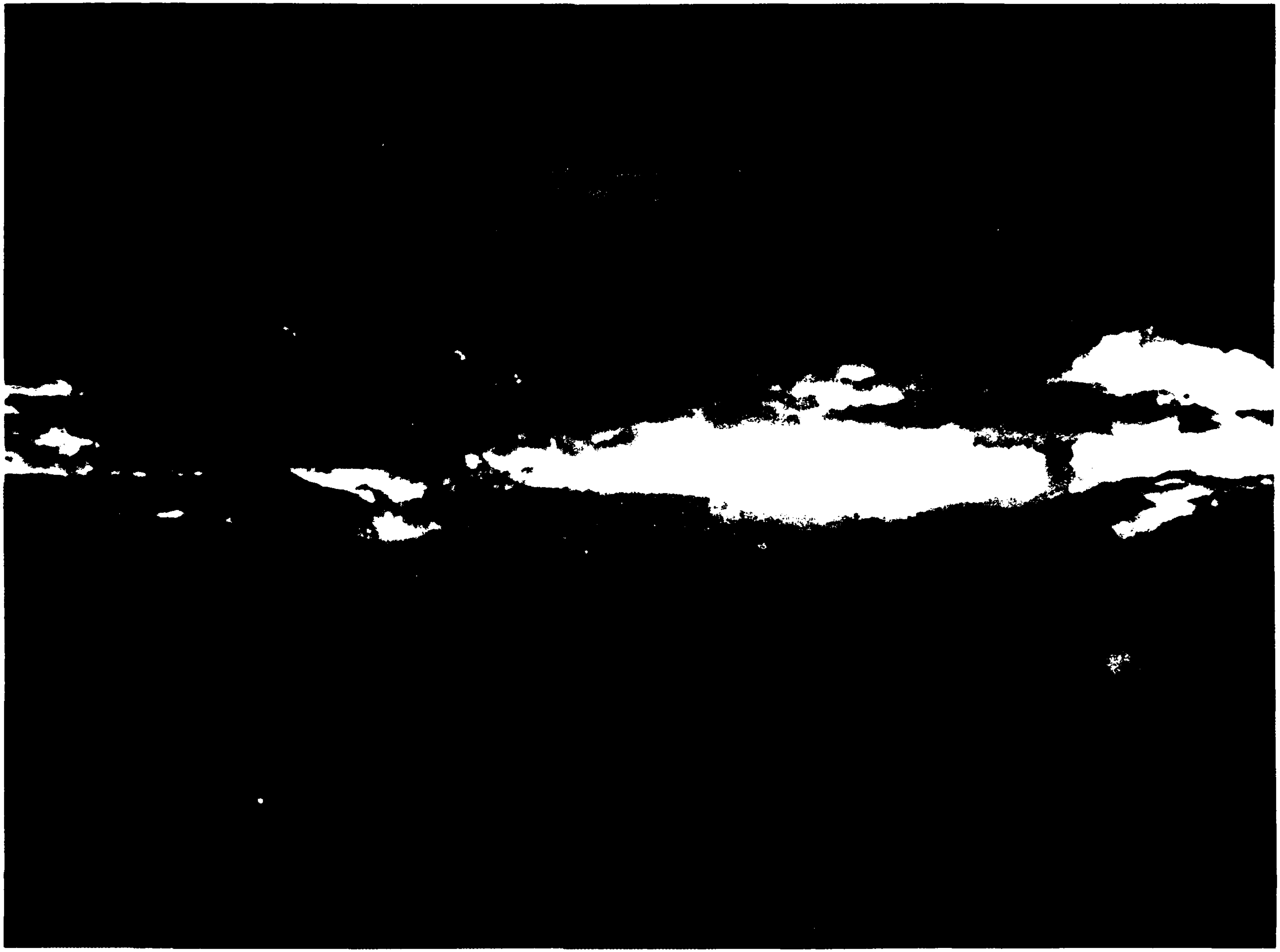


Figure 27. Photograph Looking Toward the Mass of Weather Located 20 Miles South of ZZV.

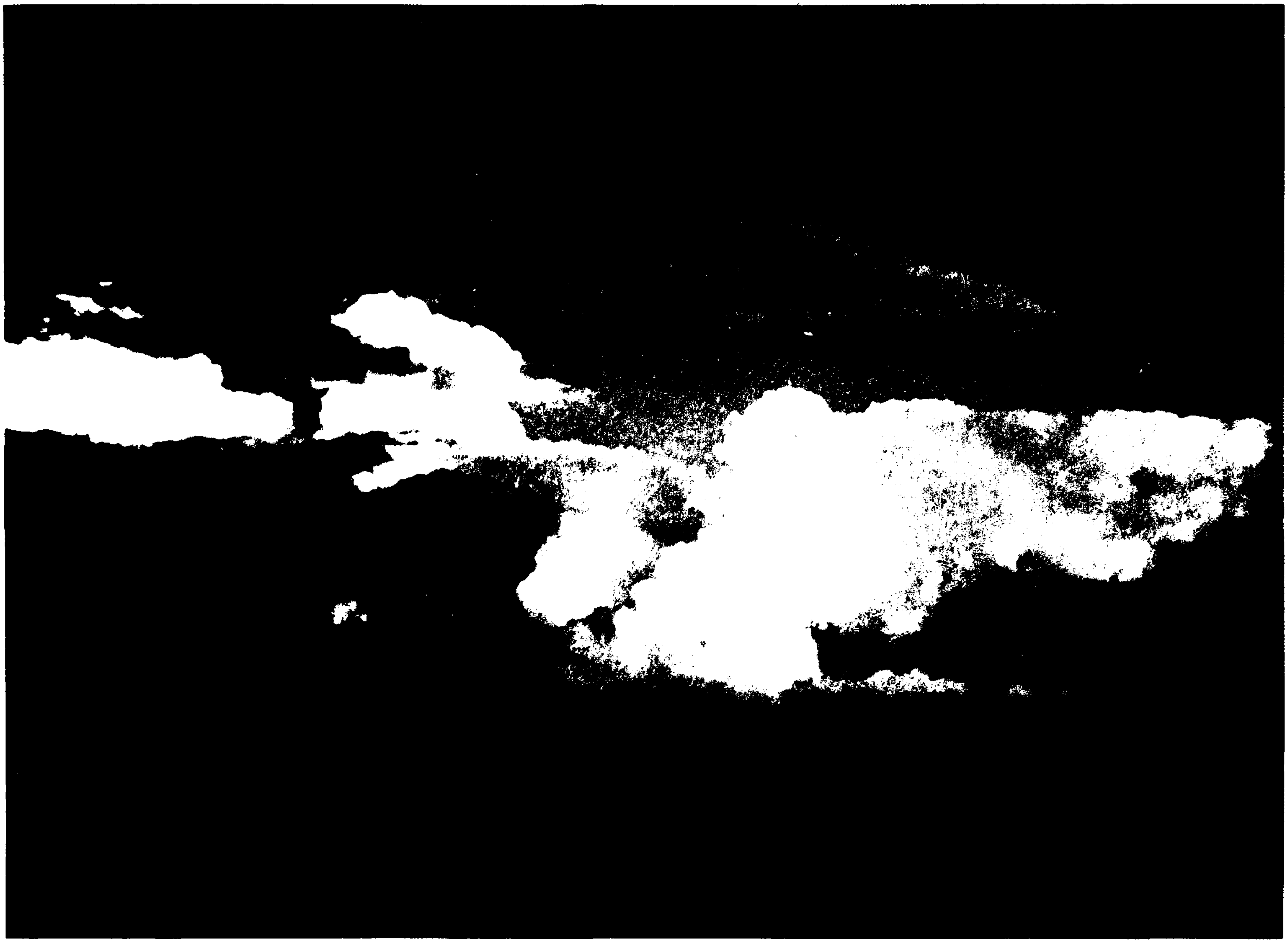
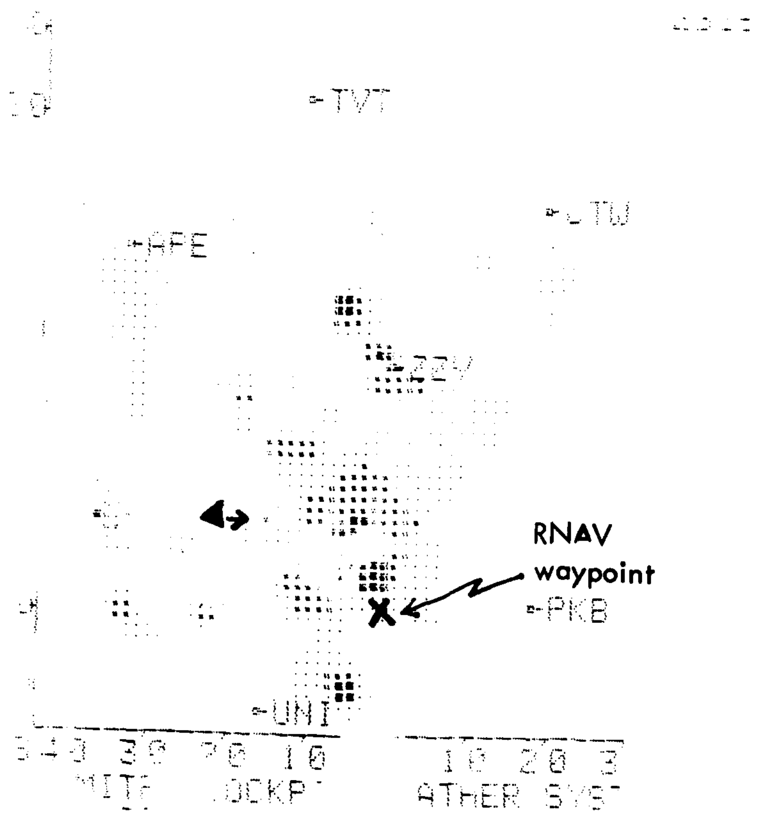


Figure 28. Photograph of Southern Edge of the Weather Mass Looking Towards the Waypoint 30 Miles South of ZZV. This view reveals opportunities for deviating south of cell.



indicates photo   aircraft position moving

Figure 29. Waypoint Has Been Added to the Printout to Provide the Reference for the Correlation With Figure 28.

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between cloud layers as depicted in Figure 30 which degenerated to essentially IMC as the photograph in Figure 31 shows.

The flight turned south after passing the waypoint 180/30 and remained in IMC. Light rain and light turbulence were present most of this route segment but this did not show well on the radar reflectivity patterns, the most representative of which is given in Figure 32. There may have been some shielding by a level 2 area just to the west 20 miles.

The flight proceeded south to intercept and track inbound 250 degrees on the UNI NDB. The radar uplinked picture was adjusted to bring the center of the coordinates to the UNI location. By doing this, it provided the advantage that the center of the coordinate system is at the point of greatest interest to the pilot, viz., the area of intended landing. This radar picture is shown in Figure 33. Expanding the scale clearly reveals the open area that was found northeast of UNI. This is precisely the area being flown in which multilayered clouds with light rain existed. This light rain did not show on the radar picture. While rain existed at the beacon, no rain had fallen at the Ohio University Airport 5 miles to the southwest. Driving back to Athens nearly one hour later revealed that while no rain existed at the airport then there was still light rain in the vicinity of the UNI NDB.

While on the approach to the airport, the stormscope showed all activity to be south of the airport. The radar picture of 2344 GMT, given in Figure 34, depicts a level 3 mass just north of the Henderson (HNN) VOR. This is consistent with the stormscope; however, this could not be confirmed visually, probably because of the poor visibility from the flight altitudes which contained extensive fractocumulus cloud formations. The electrical activity of the cells near Zanesville had apparently diminished.

Some general comments are in order. First, it should be noted that during the whole flight, part of which deliberately skirted a rather large, active mass of weather, the maximum turbulence encountered was light. Brief moments of moderate rain near the waypoint was the most intense rain that was encountered.

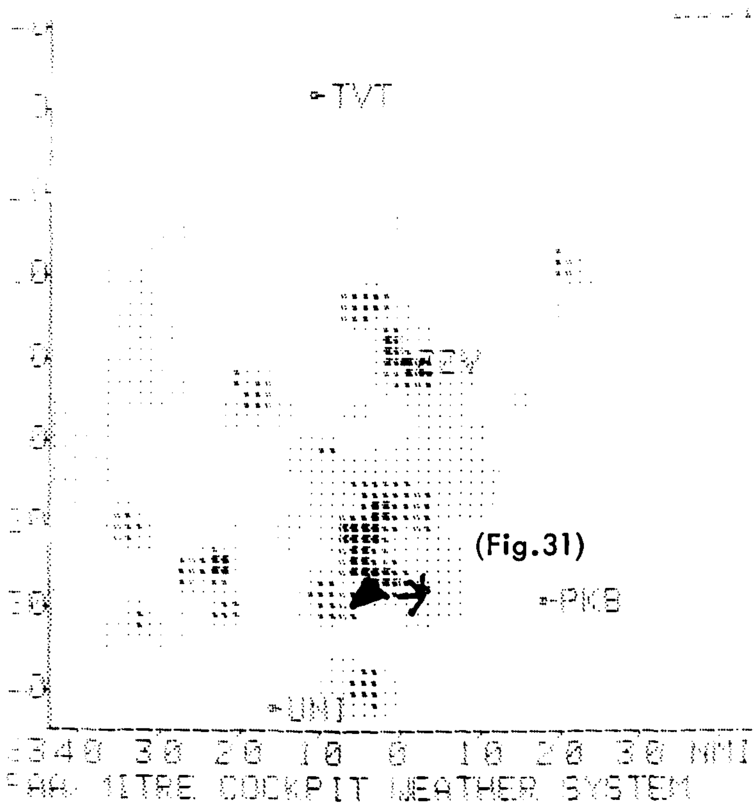
Some of the time, especially early in the flight, visibilities were great enough that there was no problem avoiding any weather. Significantly, however, the latter part of the flight involved much IMC, and it was not possible to navigate visually to avoid weather. Complete dependence, therefore, had to be placed on the CWDS. No help was solicited from the center because of the burden that was already placed on them by the flight route requirements for flexibility.

An important point became evident on this flight in particular. Even though the radar picture is not depicting rain, light rain may be found to exist such that VFR flight cannot be accomplished.

Both the radar picture and the Stormscope indicated a decrease in the activity associated with the weather mass south of Zanesville so that good consistency between the two appeared to exist. On the contrary, Stormscope

Figure 30. Entering IMC Conditions Near Waypoint.

Figure 31. IMC Conditions Near Waypoint.



→ indicates photo ▶ aircraft position moving

Figure 32. Later Picture Showing the Destination Airport Free of Weather.

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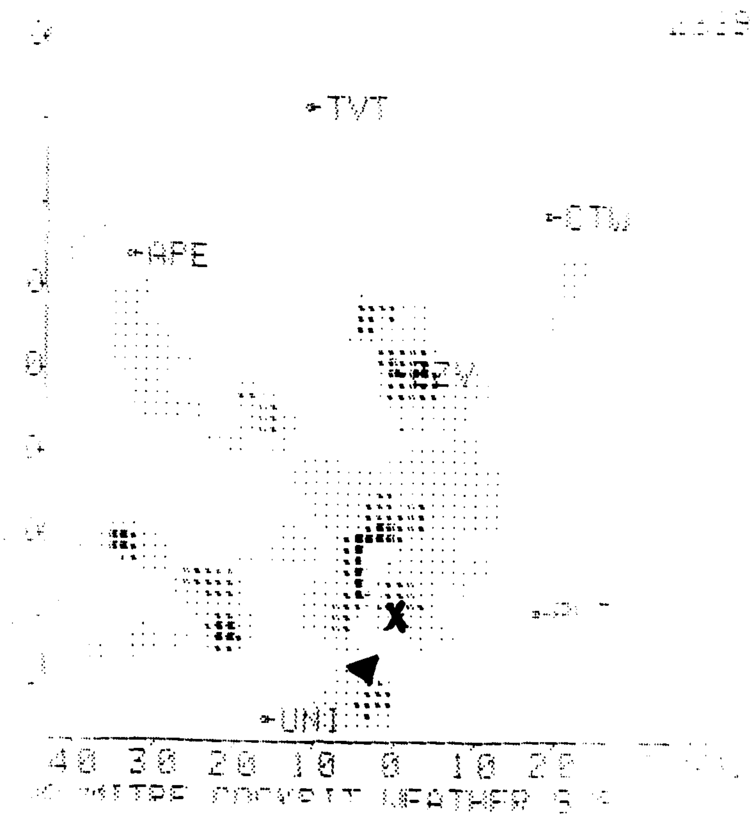

aircraft position moving

Figure 33. Expanded Scale Was Provided to Show More Detail of the Weather to be Encountered on Route to UNI Destination. IMC 8000' Rain.

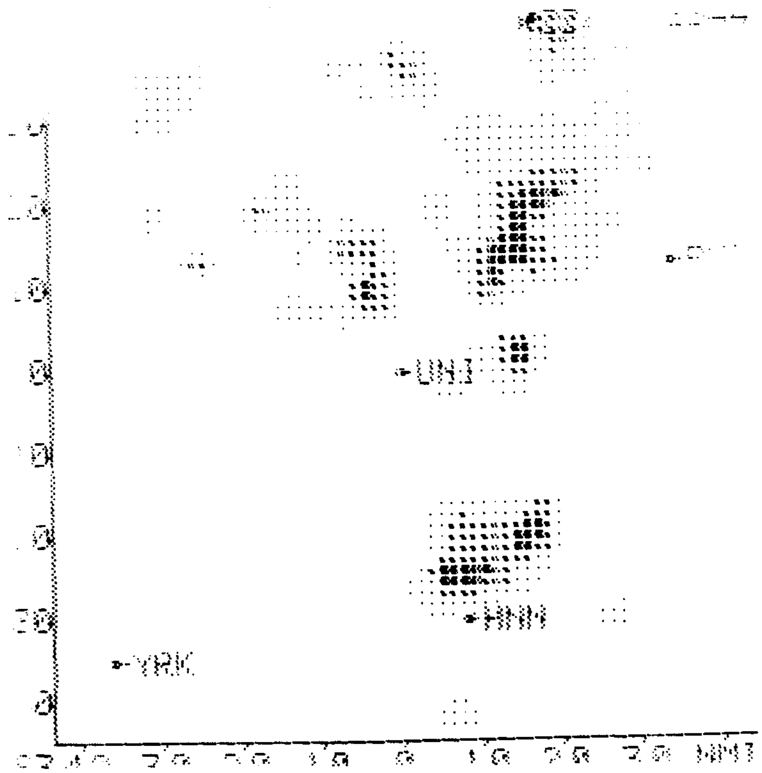

Figure 34. Printout of Coordinate Center at UNI Showing Weather Cell to South Near Henderson.

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showed the weather south of UNI to be increasing during the one hour of flight time but the weather radar did not show much change. The 100+ mile range from the rain to the C-band radar site may have been a factor.

VI. RECOMMENDATIONS

From the work performed during this evaluation program several recommendations can be made. The objective is to provide, ultimately, for a quality, pilot aid which will materially improve flight safety especially for general aviation.

1. The CWDS design should be made more appropriate for GA cockpit use and the design hardened.

2. More extensive flight evaluations should be conducted with documentary track capability so that more precise correlations between flight conditions and proximity to weather masses can be made. Guidelines for pilot usage need be generated such that, with an implementation of a CWDS, improper or inappropriate application would not occur.

3. A plan should be developed which will optimize utilization of existing weather radars with certain VOR facilities. This will be important for obtaining best use of a CWDS.

4. A channel utilization plan should be developed which will insure a capability of maximum information transfer given the radio spectrum limitations.

5. Development of a list of priorities concerning information to be uplinked to the pilot on a CWDS should be accomplished.

6. Since 40% of general aviation accidents are weather related and evidence points to the fact that the pilot is sometimes the least informed of a number of concerned individuals, it is recommended that priority be given to an implementation of a CWDS using existing technology. Low technical risk will exist and relatively rapid deployment can be expected.

7. The government should consider encouraging the industry by providing a development contract with pay back features. A model is the contract that implemented the Air Traffic Control Radar Beacon Transponder.

VII. ACKNOWLEDGEMENTS

The author is indebted to Mr. Roger Jones and Mr. Lance Dale for serving as principal evaluation pilots in this work to determine the efficacy of the cockpit weather display. Additional appreciation is due Dr. Robert Lilley and Mr. Jones for their written descriptions of specific flight conditions experienced on July 19, 1982 and August 17, 1982, respectively.

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[3] "Death of the Cyclops", Professional Pilot, May 1982, p. 37.

[4] Traffic Pattern, "Ground-Based Radar in the Cockpit", Business and Commercial Aviation, May 1982, pp. 120-122 and p. 124.

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IX. APPENDICES

A. List of observers

B. Questionnaire

C. Photographs

Appendix A.

1. J. P. McVicker
2. Lance Dale
3. Robert Jones
4. J. Lynn Helms
5. Loren Spencer
6. Robert Lilley
7. Kenneth Woods
8. John Shaughnessy
9. David Hinton
10. Richard Collins
11. John Novallino
12. Mark Lacagnina
13. Tom Oneto
14. Thomas Horne
15. Duane Hart
16. Stefan Pastin

Appendix B.

QUESTIONNAIRE

Cockpit Weather Dissemination Evaluation Flights

1. General, prevailing weather conditions:

   ☐ Rain ☐ Showers ☐ Thundershowers ☐ Thunderstorms

   ☐ line squall

2. Expected weather conditions for the flight:

   ☐ Rain ☐ Showers ☐ Thundershowers

3. Conditions encountered:

4. Was capability available to avoid undesired areas?

5. Were avoidance maneuvers successful?

6. Did the CWDS provide useful information?

7. Did the CWDS provide the essential information for maneuvering?

8. Do you trust the CWDS?

9. Was the information from the CWDS consistent with other weather information you may have received?

10. Was the range of the CWDS adequate?

11. Did three VOR's provide adequate coverage?

12. Was the data format satisfactory for your interpretation and use?

13. What was the principal deficiency or shortcoming that you felt existed with the CWDS?

14. In your opinion the availability of the weather information from the CWDS would:

☐ greatly enhance ☐ enhance ☐ not affect ☐ degrade

the safety of the flight.

15. Please add any comments that you feel would be helpful to the FAA as they deliberate on the desirability of implementing such a system.

Name: ______________________________

I.P.: ______________________________

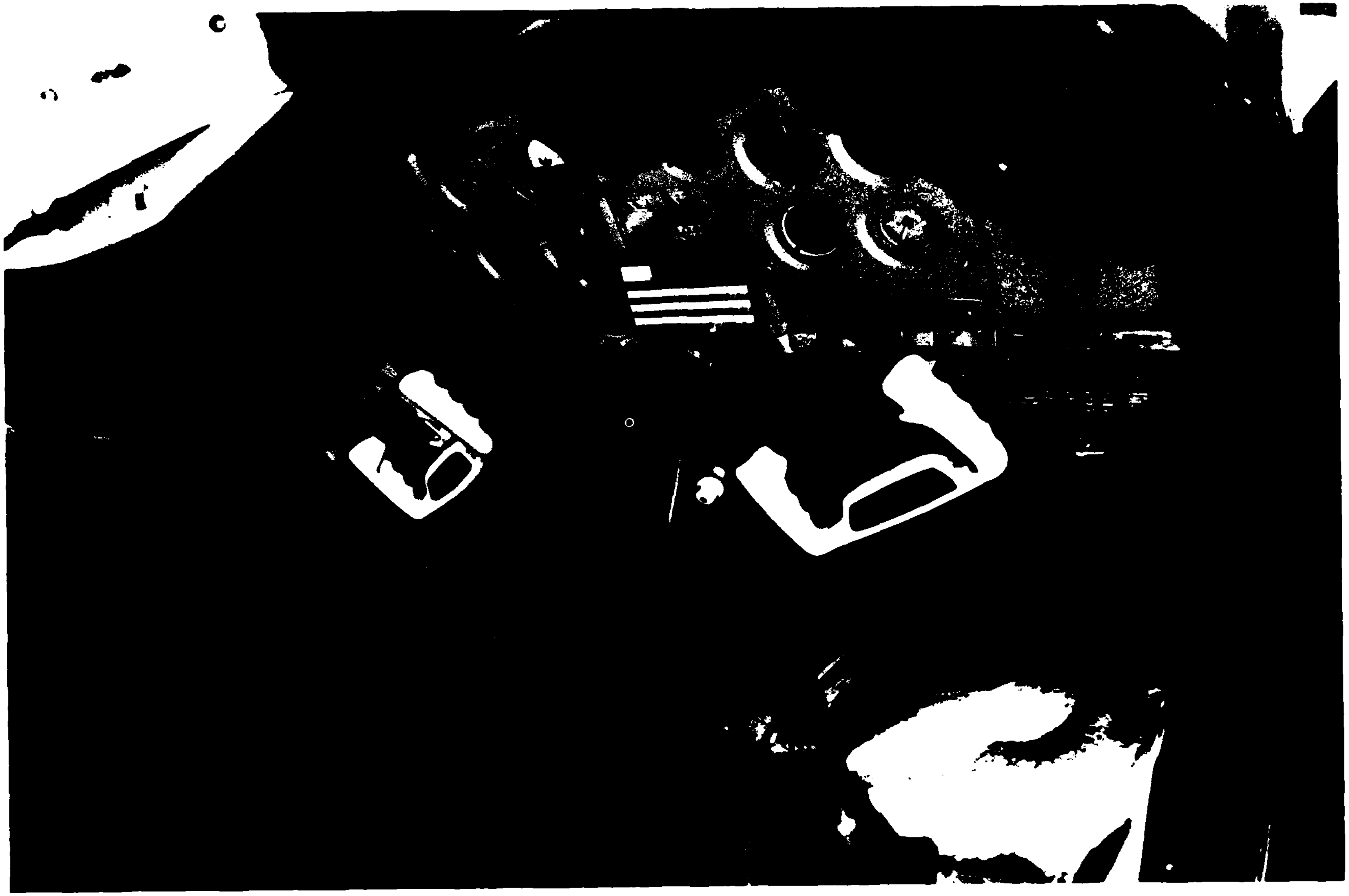

Figure C-1. Photograph Showing Position of Keyboard/Display in Beechcraft Bonanza.

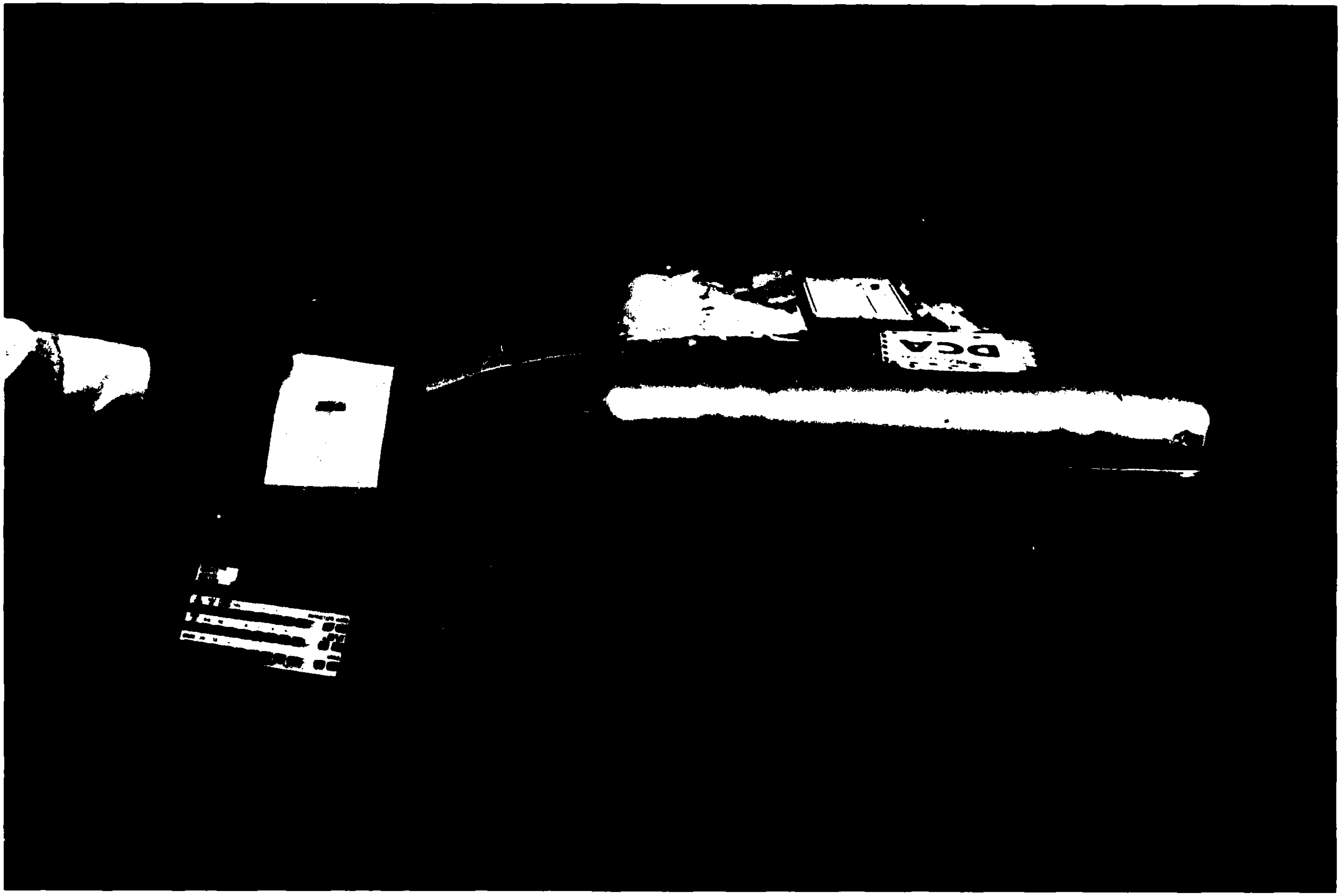

Figure C-2. Photograph Showing the 3 CWD Components on Lab Bench.

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